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GREENHOUSE HEATING

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INTRODUCTION

For several years past the department has been interested in problems of greenhouse construction and heating,[1] both from the standpoint of aid to individual growers and in connection with its own experimental work, which requires the use of many greenhouses of different types. In 1929 a survey was made of greenhouse heating methods in the District of Columbia, Maryland, Pennsylvania, New York, Massachusetts, Ohio, and Indiana, which showed that, while heating installations by qualified specialists in greenhouse heating were almost uniformly satisfactory, many greenhouse heating plants were not properly installed and did not function efficiently. This circular is intended to aid in the design and improvement of greenhouse heating plants. It presents standard engineering data on this subject and practical information with regard to the layout and operation of modern heating systems.

REQUIREMENTS OF A GREENHOUSE HEATING PLANT

The demand for heat in a greenhouse fluctuates greatly. When the sun shines brightly little artificial heat is needed, and the heating plant must be cut down in some way to prevent overheating with resulting waste of fuel and injury to the growing plants. A system in which the heat is easily controlled may be termed flexible; the more flexible it is, the more effectively the desired temperature within the house can be maintained. Many of the claims made for certain types of heating systems are based on flexibility.

The desirable temperatures for various types of greenhouses are given in Table 1. While many growers have developed methods of their own which call for temperatures somewhat different from those

[1] Beattie, J. H. greenhouse construction and heating. U. S. Dept. Agr. Farmers' Bul. 1318, 38 p., illus. 1923.

given, the table is believed to be sufficiently accurate to serve as a basis for heating-plant estimates.

TABLE 1.—*Customary temperatures for different types of greenhouses*

Type of house	Temperatures From—	Temperatures To—	Type of house	Temperatures From—	Temperatures To—
	° *F.*	° *F.*		° *F.*	° *F.*
Carnation	45	55	Orchid, cool	50	55
Conservatory (general collection, winter, garden, etc.)	60	65	Palm, warm	60	65
Cool	45	50	Palm, cool	50	55
Cucumber	65	70	Propagating	55	60
Fern	60	65	Rose	55	60
Forcing	60	65	Sweet pea	45	50
General purpose	55	60	Tomato	65	70
Lettuce	40	45	Tropical	65	70
Orchid, warm	65	70	Violet	40	45

HEATING SYSTEMS

The principal types of heating successfully employed in greenhouses at present are hot water and steam. The use of stoves and flue heaters is discussed in another bulletin of this department.[2] Hot-water heating plants are of two kinds—gravity circulation and pump circulation. Steam-heating plants are of several kinds, the main distinction being the manner in which condensed steam is returned to the boiler. Boilers for all types are much alike.

The relative advantages of the several types of systems are not always clear in the minds of the growers. For example, the field investigations revealed that certain carnation growers in New England insist on a vacuum-return type of steam-heating system with heating lines under the benches, while in other parts of the country the growers prefer the comparatively low-radiation temperatures obtainable with the hot-water system. Generally the hot-water system is the more satisfactory where the size of the greenhouse is not too great. For the larger ranges in which the heat must be carried greater distances, the steam system is probably more flexible, and cheaper to install because of the smaller pipe sizes. In the gravity-circulation hot-water system the danger of breakdowns is probably less because the system is not under pressure. Small leaks in a hot-water system can be repaired while operation continues, and even in case of a complete shutdown of the system a reasonably safe temperature often can be maintained for several hours. Each system has definite operating characteristics, which should permit the grower to choose a type adapted to his particular needs. Descriptions of the systems are given herein to bring out characteristics that have a direct bearing on the problem of greenhouse heating. Certain pertinent facts having direct reference to a number of the greenhouses studied are also presented.

STEAM-HEATING SYSTEMS

The steam-heating system is perhaps the simplest to design and install. The steam passes from the boiler through pipes into the

[2] BEATTIE, J. H. Op. cit.

radiators.[3] The steam gives off heat to the radiators, and condenses into water which flows back to the boiler through the return pipes.

One of the principal disadvantages of the ordinary steam system is the fact that only while steam is being generated is heat emitted from the radiators, which means that the radiators either are at a temperature of 212° F. or more, or else are cold. Steam installations, therefore, unless fitted with oil burners or stokers and with automatic temperature control, require more attention than other systems. An advantage of the steam system lies in the fact that heat can be put into the house very rapidly when required, as in case of an abrupt drop in outside temperature. On the other hand, since the quantity of heat contained in the steam is comparatively small, the mere closing of a valve immediately shuts off the heating effect. This characteristic is of value when the sun is on the glass and it is desired to hold down the temperature. A diagrammatic layout of a simple gravity-return steam plant is shown in Figure 1.

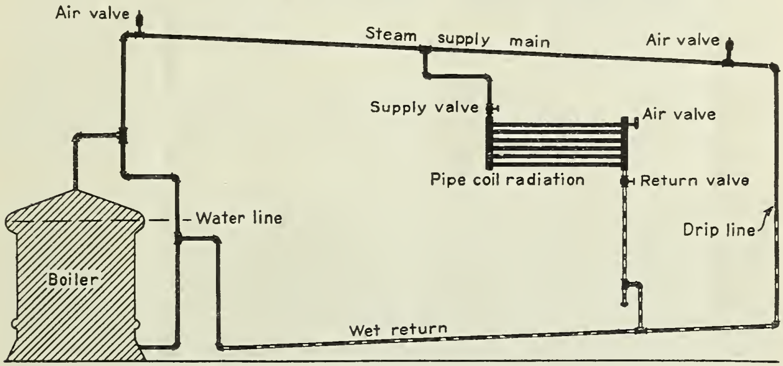

FIGURE 1.—Diagram of a gravity-return steam-heating system. If the boiler is set in a pit, the return line will be higher

The radiator has a control valve at the inlet and either a control valve or a check valve or both at the outlet to the return line. Air-relief valves are located on the radiators and on the main. One disadvantage of this system lies in the fact that, since the return of the condensate to the boiler is by gravity, there must be a vertical clearance of 2 feet or more between the return tapping of the radiator and the boiler-water line. To provide such a clearance the boiler must, in many instances, be placed in a pit. This difficulty can be avoided, however, by allowing the condensate to flow by gravity to a sump located at a sufficiently low level and returning it to the boiler by an automatic, float-controlled pump. With this design a thermostatic trap, which passes water but not steam, rather than the simple check valve, must be placed on each return and drip line. A diagrammatic sketch of the gravity-flow steam system with pump return to boiler is shown in Figure 2.

Figures 3 and 4 show some of the piping details of a well-designed and well-built gravity-return steam heating system in a rose house.

[3] Greenhouse men commonly refer to their piping, whether in single lines or multiple lines, as "coils." Pipe coils are referred to throughout this circular as radiators.

Both the house and the heating system were designed and constructed by greenhouse specialists. The circulation of steam and condensate is effective and quiet, as the result of good proportioning and grading of mains. The boiler-room floor is approximately 9 feet below the level of the greenhouse floor at the boiler-room end.

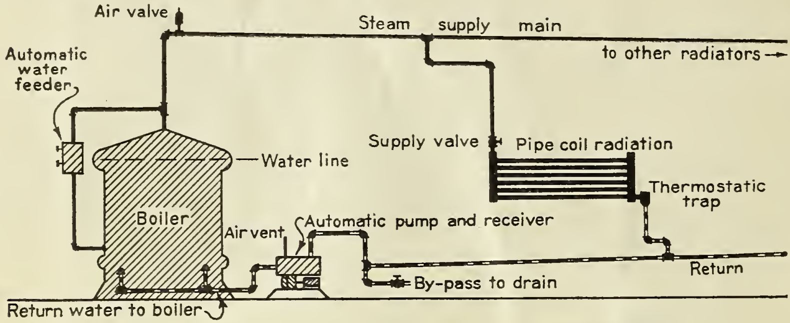

FIGURE 2.—Steam heating system with condensate pump

The steam and return mains are placed in a trench along the ends of the houses. Figure 3 shows the up-feed risers extending upward from the main in the trench and connected into the two horizontal

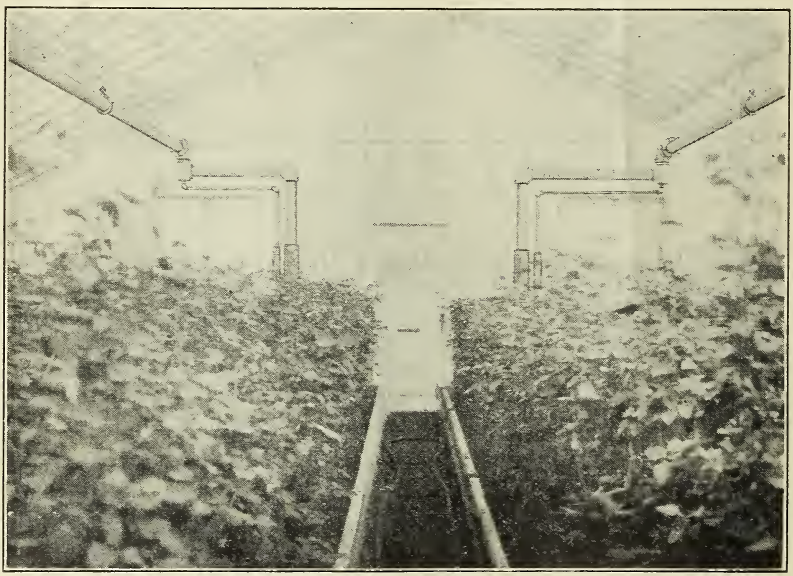

FIGURE 3.—Supply riser piping for low-pressure steam

feed lines which run the full length of the house. The horizontal mains are pitched upward from the risers, so all the condensate in the mains flows back against the direction of the steam flow. This condensate is caught in the tees and passed into the return by means of the drip line. With the type of hanger and method of piping

used, free expansion by movement on threads can take place without causing water pockets or straining supporting members.[4] One of the longitudinal heating lines along the beds also can be seen in the illustration. The insulation on the risers at the ends of the beds extends only part way up, merely to provide protection to persons and plants.

The opposite end of the house, where the horizontal mains terminate in smaller branches which feed down to the heating lines along the beds, is shown in Figure 4. On each of the vertical down feeds can be seen the gate valve which serves to cut out the line. This plant was in general well planned and installed, and the return of condensate to the boiler was facilitated by the arrangement and grading of pipes.

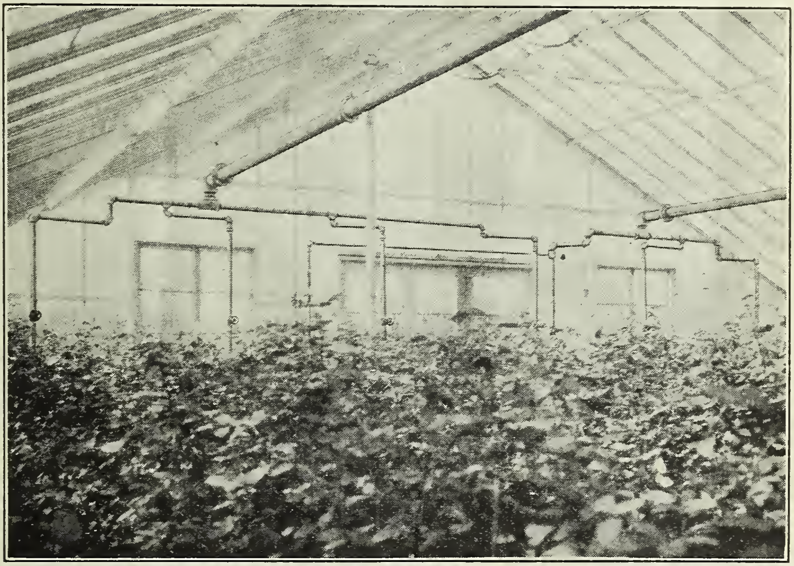

FIGURE 4.—Down-feed piping for low-pressure steam

The method of collecting the returns at one end of a rose house having a low-pressure steam system is shown in Figure 5. The condensate passes from the coils into the smaller lines, then through the swing check valves and into the steam trap, from whence it passes to an automatic pump which forces it back into the boiler. In this particular range of houses the trap was of the high-pressure type, which was a poor choice. The high-pressure trap costs considerably more than the low-pressure type of similar capacity. In this house no provision was made for expansion of the mains when steam was turned into them. This resulted in the bowing of the supply lines and trapping of water in the sagged portions. This obviously decreased the capacity of the steam main and also put undue strain on certain fittings, thereby needlessly increasing the danger of breakage.

[4] For practical purposes it is sufficiently accurate to assume, in connection with greenhouse heating systems, that the maximum expansion of steam or water pipes will be 1¾ inches per 100 feet of pipe.

A more workmanlike scheme for grouping the returns from separate steam-heating lines is illustrated in Figure 6. This also is a low-pressure, gravity-return steam system. In this installation dirt pockets are provided just ahead of the swing check valves.

The adequate venting of air from steam-heating systems is important. Air is a poor conductor of heat, and a radiator largely filled with air is ineffective. Moreover, air pockets may prevent circulation of the steam. The manual venting of steam radiation is usually effected by means of brass pet cocks. When the heating system is started these cocks should be opened fairly wide, but after the required steam pressure has been reached they should be kept nearly closed.

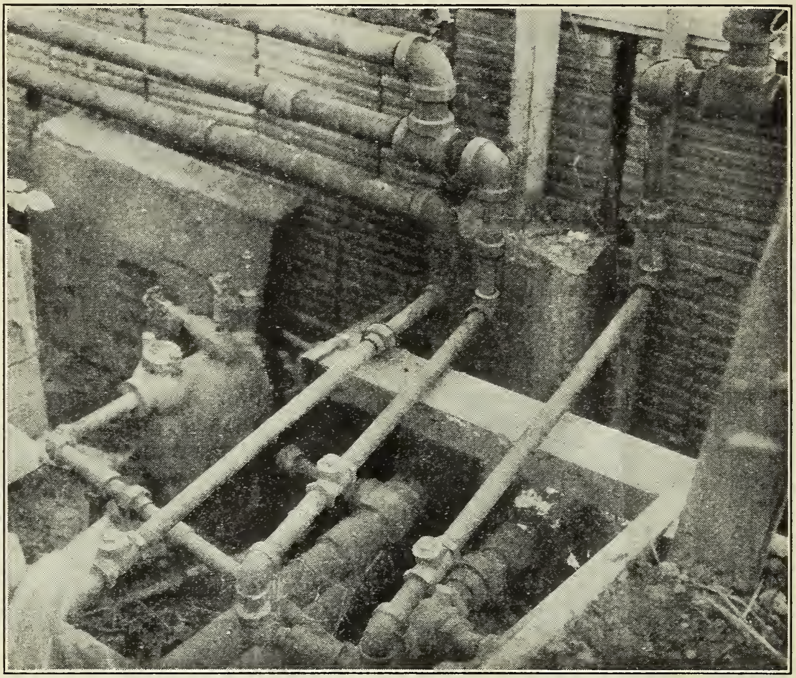

FIGURE 5.—Return connections to steam trap

The automatic air valve is generally of a type somewhat different from the valve of the conventional domestic radiator. Its operating principle is the expansion of a carbon element, and it is generally installed in combination with a pet cock. When the system is started the pet cock is used for rapid venting, and after the residual air is eliminated the pet cock is closed and the automatic element serves. The automatic valves are sturdy and are reasonable in price, and the continuous venting they provide is more satisfactory than that accomplished by the intermittent opening of pet cocks.

VACUUM-RETURN STEAM SYSTEM

The vacuum-return principle is advantageously employed in some of the largest greenhouses in the United States for removing con-

densate from the heating coils and returning it to the boiler. This system is illustrated in Figure 7. The steam is generated and delivered to the radiators in the usual manner, but a partial vacuum is maintained at all times in the return system by power-operated pumps. The vacuum facilitates positive removal of the condensate from the radiators and at the same time permits the condensate to be raised to considerable heights by means of so-called " lift " fittings. To maintain a vacuum in the return system, steam must be excluded. Therefore, on the return of each radiator and on every drip from the main risers a thermostatic trap is installed.

The vacuum system lends itself very well to automatic temperature control by means of motor-operated valves. The condensate is

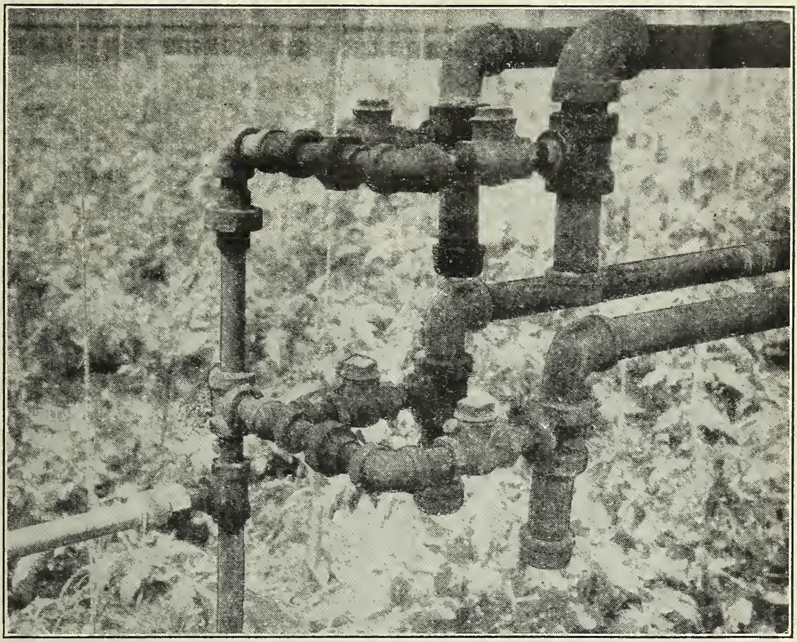

FIGURE 6.—Use of check valves in grouping returns

effectively removed from the radiators, and the alternate opening and closing of the steam-supply valves produce very little noise from water hammer. With the vacuum system the circulation is strong and positive; the venting of the air is effected at a central point.

A method of installing thermostatic traps at the ends of the heating lines along the beds in a cucumber house is shown in Figure 8. From these traps the condensate passes into the return main in the trench under the planks. These return mains lead to the vacuum pumps in the boiler room.

In some cases the natural slope of the ground permits the return to be made by gravity to a sump or hot well from which it can be returned to the boiler by a pump which is generally, and preferably, automatic in operation.

In some cases it is found expedient to convert from a gravity-return steam system to a vacuum-return type. In fact, this sometimes becomes necessary when a system is so enlarged that the circulation

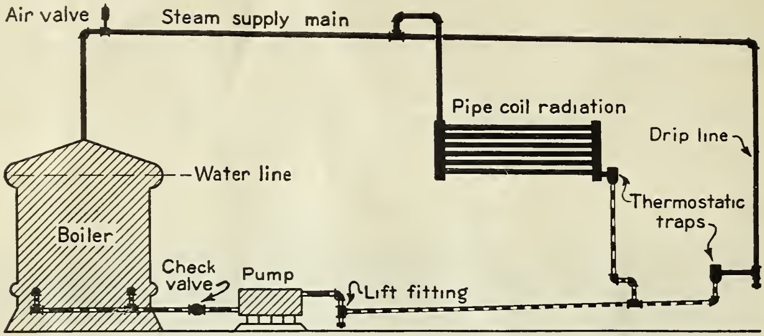

FIGURE 7.—Steam-heating system with vacuum pump on return line

of steam and condensate becomes sluggish. An instance of such a conversion, planned by the author, is that at the Arlington Experiment Farm of the Bureau of Plant Industry of this department. The

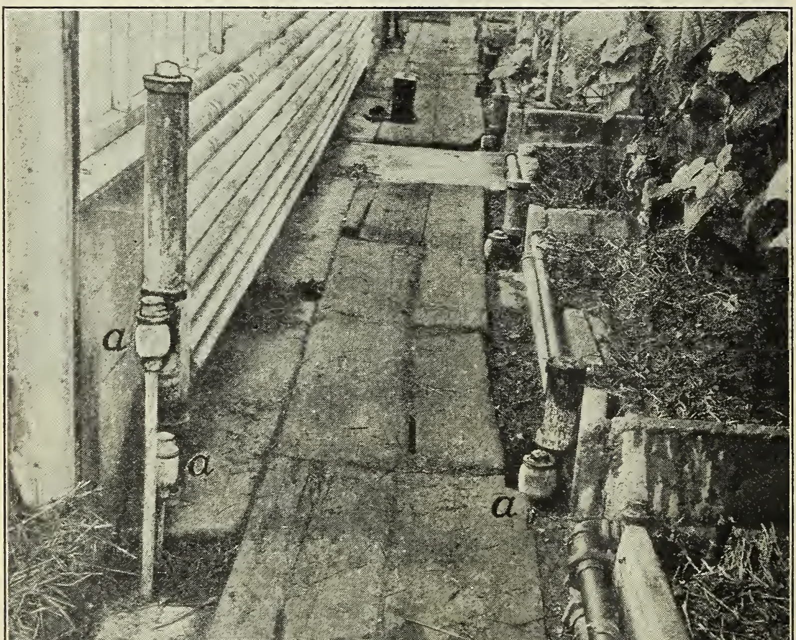

FIGURE 8.—Thermostat traps (*a*, *a*, *a*) applied to vacuum-heating system

layout consists of a number of greenhouses and other buildings which are heated by a low-pressure steam plant with four 150-horsepower boilers. Originally the condensate was returned to the boiler by gravity, but as the length of runs and the total load increased the

return of the condensate became sluggish, and in some portions of the plant the radiators were completely filled with water. To convert this plant to the vacuum system, each drip and radiator was fitted with a thermostatic trap, and in the boiler room were installed two vacuum pumps, each of which has a capacity of 40,000 square feet of equivalent cast-iron radiation. A vacuum is maintained in the return line at all times, and the return of condensate to the boiler is satisfactory.

HOT-WATER SYSTEMS

The body of water used in a hot-water heating system constitutes a large reservoir of heat. In many of the smaller plants, particularly those devoted to the growing of flowers, very little attention is given to the firing of the boilers at night. In such plants the large heat capacity of the water system permits safe temperatures to be carried throughout the night with a minimum of attention. When it is desired to hold the temperatures down, however, the stored heat becomes a disadvantage.

Hot-water heating systems are of two general types, gravity circulation and forced circulation.

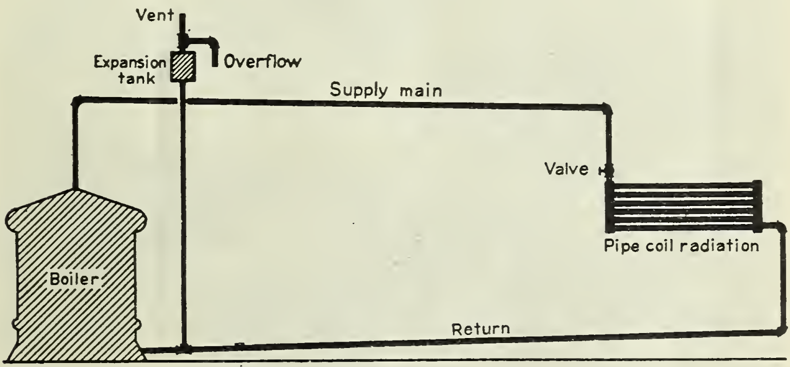

FIGURE 9.—Open hot-water heating system

GRAVITY CIRCULATION

A gravity-circulation system may be either "open" or "closed." The simplest type of open hot-water system is shown in Figure 9. The elevated expansion tank, open to the air, is an essential part of such a system. It allows change in volume of the water as its temperature changes, and permits a certain amount of venting of air from the system. The radiators also are provided with air vents, which in most cases are manually operated.

In a closed hot-water system the expansion of the water is taken care of automatically by a relief valve. Sometimes a closed expansion tank containing air is also used. A deficiency of water in the closed system is generally made up automatically from a supply under pressure. In the closed system the pressure maintained is somewhat higher and the temperature permissible is also higher than in the open system. Because of the higher temperatures maintained, the

circulation in a properly installed closed system should be somewhat more positive than that obtained in the open system.

Opinions differ as to the relative merits of the open and closed systems of hot-water heating. The field study showed that at the present time practice favors the open system. The views expressed by various greenhouse operators indicated that failure to adopt the newer closed type was due chiefly to reluctance in adopting an innovation. However, use of the closed system undoubtedly is increasing in greenhouse as well as domestic heating practice. Elimination of the high-expansion tank is generally an advantage, and with the closed system the pipe sizes and quantity of radiation required are less than with the open system.

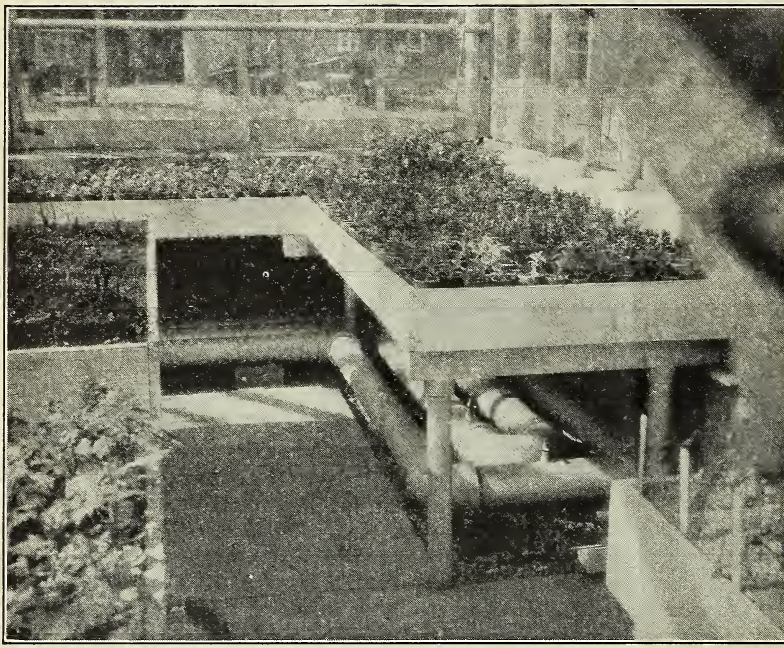

FIGURE 10.—Arrangement of hot-water radiation under benches

In the gravity hot-water system the temperature of the water is usually only about 160° F. More radiating surface therefore is required than in the case of steam heat. The piping for hot-water radiation is frequently, in small greenhouses, 3½-inch cast iron, hub and spigot. The reasons for using such equipment are its long life and its large capacity for retaining heat during the night with little or no attention to the fires. In the smaller commercial houses 2-inch pipe, either wrought iron or wrought steel, is largely used. Figure 10 shows the installation of two U-shaped lines of 3½-inch cast-iron radiation under benches. The brass pet cocks are for air relief, and are placed at the high end of the radiation.

The fires of small greenhouses, heated by the open-type system, usually do not have close attention at night. For this reason they should be designed for a comparatively low-average radiator-water

temperature (160° F.) rather than for the higher temperatures which have been recommended for domestic practice in recent years.[5] This is one of many phases in which greenhouse heating practice differs from residence heating practice.

FORCED CIRCULATION

In large greenhouses gravity circulation of water is impracticable, and circulation is effected in a positive manner, usually by means of steam-driven reciprocating pumps. Large plants generally contain several boilers, one of which is used to supply steam to operate the pumps, while the others are merely water heaters. It is possible to achieve accurate temperature regulation in three ways, namely, by controlling the fires, by controlling the speed of the pumps, and by regulating the supply valves affecting the various

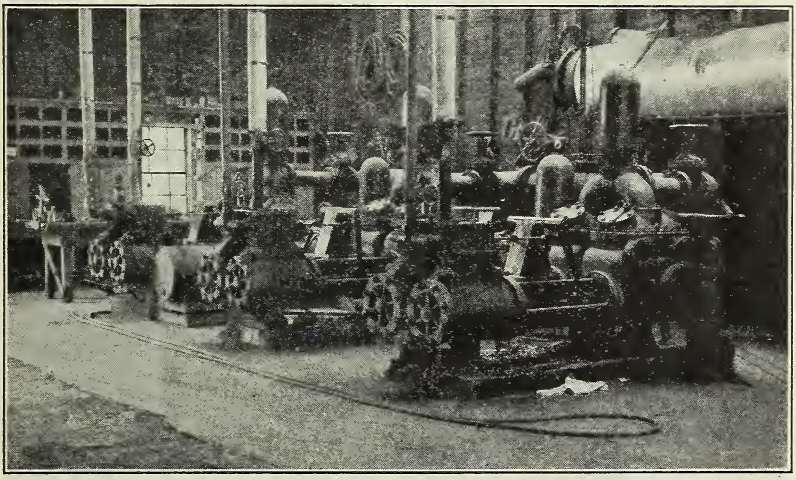

FIGURE 11.—Reciprocating pumps of forced-circulation hot-water system

houses. Moreover, when several houses or groups of houses in a range are to be maintained at different temperatures, the valves controlling the flow in the various houses need seldom be adjusted, the temperatures of the entire range being controlled chiefly by regulating the fire or by controlling the speed of the pumps.

Figures 11, 12, and 13 show features of one type of forced-circulation hot-water system operated successfully in vegetable-growing houses of approximately 7 acres. The houses are of the ridge-and-valley type. The power plant consists of four 150-horsepower boilers. One of these boilers is used to supply steam for the operation of the hot-water circulating pumps, and when required it also supplies steam for soil sterilization. The other three boilers are used to heat the water which is circulated through the heating system. The arrangement is such, however, that any one or more of the boilers can be used to generate steam while the others heat the water.

[5] AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS. . . . GUIDE, 1932. 876 p., illus. New York. 1932.

The arrangement of pumps and the feed-water heater, in a room adjoining the boiler room, is shown in Figure 11. The method of taking off the flow and return connections from the flow and return mains is shown in Figure 12. The 10-inch overhead flow main is completely inclosed in a boarded housing, and the 10-inch return main

FIGURE 12.—Flow and return piping of a forced-circulation hot-water system

is in a trench under the planking. The overhead branch flow line, located immediately below the gutter between the two houses, is a single line running the full length of the house. At the far end it drops into the four return pipes which serve as the principal heating surface. The only valves provided for the radiation in the houses are those shown. Vertical banks of coils are placed along the con-

crete side and end walls, as shown in Figure 13. This view shows also a satisfactory method of bridging the crosswalks in the houses when forced circulation is used. The four return lines are united in one, which is looped over the walk at a height sufficient to give headroom; this scheme could not be used in the gravity-return system on account of the interference with circulation.

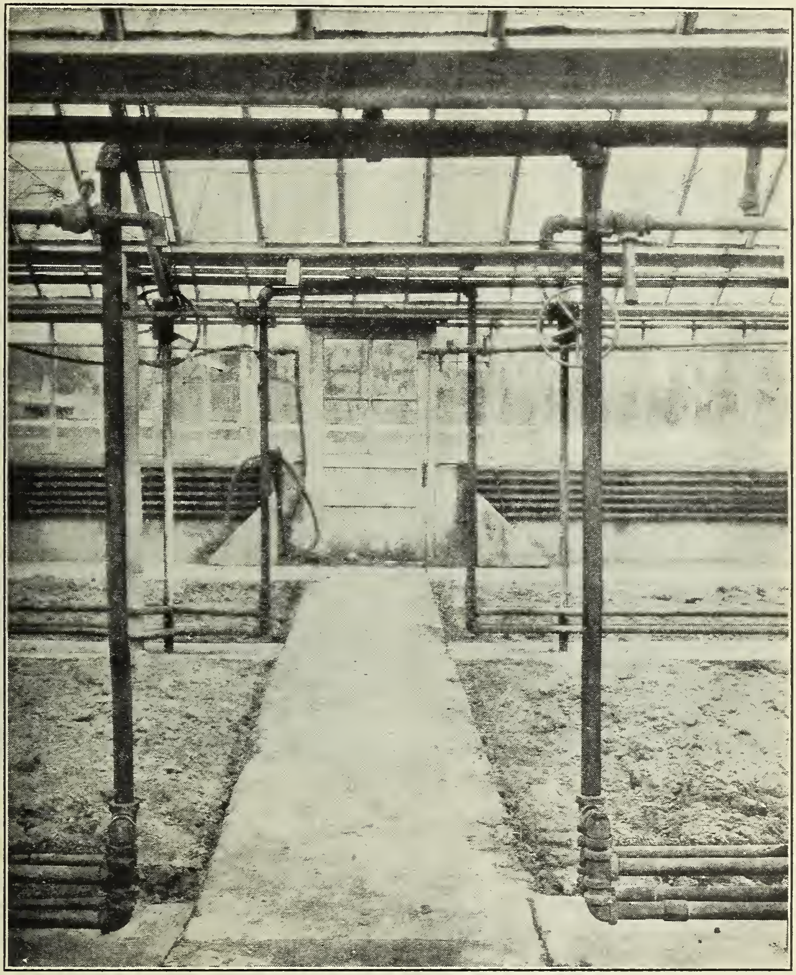

FIGURE 13.—Side-wall radiation and method of bridging walks

A method of arranging forced-circulation hot-water radiation in a cucumber house is shown in Figure 14. The flow radiation is hung on one side of the line of columns, while the return is on the other side. The radiation runs the full length of the house, and all the control valves are at the one end. No shading results from this arrangement of heating piping, and since all the radiating surface is low the heat given off is utilized more effectively than in the previous example, in which the flow line is overhead.

A simple forced-circulation device has been used with considerable success in the design of small oil-fired hot-water systems where it was not feasible to place the boiler at a depth which would assure the brisk circulation especially desirable in an automatically controlled oil-fired plant. In such instances a small motor-driven circulator placed in the return or in the flow line produces the desired degree of circulation. The electrical circuit of this motor is connected to the oil-burner circuit in such manner that the circulator functions when the oil burner is operating and ceases to function when the burner stops. It is also feasible, of course, to operate such a circulator manually and to use it in connection with a coal-fired job.

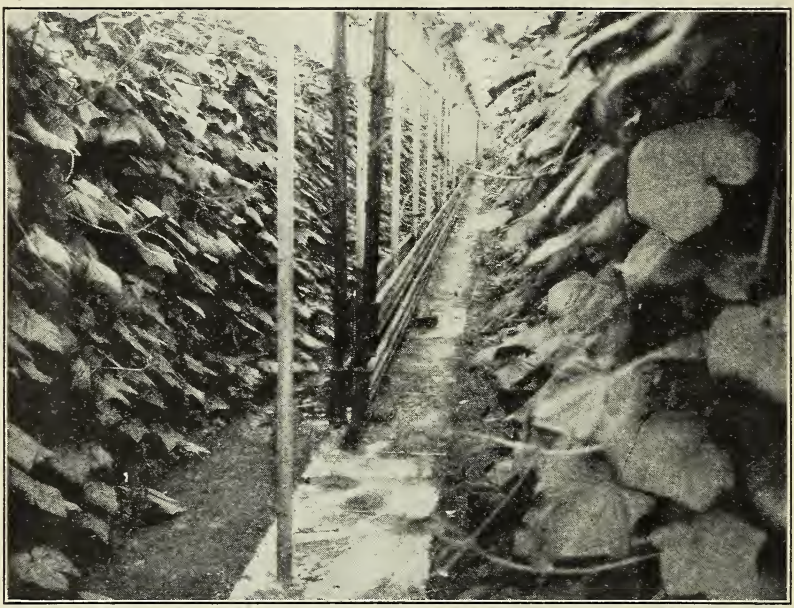

FIGURE 14.—An arrangement of radiation in a forced-circulation hot-water system

MAXIMUM HEAT REQUIREMENTS

The maximum rate at which heat must be supplied to a greenhouse depends on the inside temperature to be maintained and the lowest outside temperature that is likely to occur. Knowledge of the maximum heat requirement for a given area of glass is particularly useful in estimating the boiler capacity required for a given plant. This requirement can not well be stated in terms of boiler horsepower, because that term is too vague. For example, a given boiler may have widely different ratings, according to whether it is fired by hand or by stokers, or whether pulverized fuel or oil is used. Table 2 gives the number of British thermal units [6] required per hour to maintain various inside temperatures for a unit of 1,000 square feet of glass, with outside temperatures from 20° to −30° F.

[6] For practical purposes a British thermal unit may be taken as the heat necessary to raise the temperature of 1 pound of water 1° F.

TABLE 2.—*Heat required to maintain greenhouse temperatures, per 1,000 square feet of glass*

Temperatures to be maintained in house (° F.)	Heat required per hour at—					
	20° F. outside	10° F. outside	0° F. outside	−10° F. outside	−20° F. outside	−30° F. outside
	B. t. u.	*B. t. u.*	*B. t. u.*	*B. t. u.*	*B. t. u.*	*B. t. u.*
40 to 45	28, 600	41, 000	53, 800	66, 800	79, 200	92, 200
45 to 50	34, 800	47, 500	60, 100	72, 600	85, 300	98, 000
50 to 55	41, 250	53, 800	66, 450	79, 000	91, 700	104, 500
55 to 60	47, 500	60, 500	72, 800	85, 300	98, 500	111, 000
60 to 65	53, 700	66, 600	79, 100	91, 700	104, 500	117, 300
65 to 70	59, 700	72, 600	85, 400	98, 300	111, 000	123, 000
70 to 75	66, 250	79, 200	91, 700	104, 800	117, 500	129, 500

These requirements were computed by using a heat-transfer coefficient of 1.1 British thermal units per hour, per square foot of glass, per degree difference between inside and outside temperatures, and allowing 15 per cent for heat loss due to infiltration of cold air. In estimating heat losses through greenhouse walls other than glass it is sufficiently accurate to assume that 2 square feet of wall are equivalent to 1 square foot of glass. In using Table 2 for any proposed installation the minimum outside temperature is ordinarily assumed as 10° above the lowest recorded temperature for the locality, since extreme low temperatures occur very seldom and for very brief periods. If a steam-heating plant is to be used, Table 2 provides the data for determining the approximate quantity of steam required per 1,000 square feet of glass, since almost 1,000 British thermal units are emitted per pound of steam condensed from a gauge pressure of 5 pounds.

RADIATION REQUIREMENTS

The length of piping needed to supply heat depends on the type of heating systems and the size, location, and arrangement of the pipes. Table 3 states the heat given off per hour per 1,000 linear feet of pipe of the kinds noted, through the same range of inside temperatures as in Table 2. These figures are for arrangements of pipe usually encountered in practice.

TABLE 3.—*Heat emitted per hour per 1,000 linear feet of pipe radiation, in air at common greenhouse temperatures* [1]

Type and size of pipe radiation	Heat units per hour, at house temperatures of—						
	40°–45° F.	45°–50° F.	50°–55° F.	55°–60° F.	60°–65° F.	65°–70° F.	70°–75° F.
	B. t. u.	*B. t. u.*	*B. t. u.*	*B. t. u.*	*B. t. u.*	*B. t. u.*	*B. t. u.*
Steam, low pressure, 1¼-inch	187, 400	180, 300	173, 300	166, 300	160, 000	153, 300	147, 000
Hot-water open system, gravity circulation, 2-inch	150, 200	143, 500	135, 300	127, 700	121, 000	113, 700	106, 800
Hot-water, pump circulation, 2-inch	236, 700	227, 500	217, 500	207, 700	199, 500	190, 800	182, 500
Hot-water open system, gravity circulation, 3½-inch	245, 000	232, 300	219, 700	204, 000	193, 000	181, 800	169, 800

[1] Based on average temperatures of the heating fluid, as follows: Low-pressure steam, 220° F.; hot-water gravity circulation, 160°; hot-water pump circulation, 210°.

The amount of radiation required for a greenhouse may be computed from the data in Tables 2 and 3, by dividing the total heat requirements of the house by the heat emitted per thousand feet of pipe of the kind to be used. It is more convenient, however, to use Tables 4, 5, 6, and 7, which give the glass area that can be adequately heated by 1 linear foot of pipe. Use of these tables is illustrated by the following example.

TABLE 4.—*Area of glass exposure*[1] *that can be heated, per linear foot of 1¼-inch low-pressure steam-pipe radiation*

Temperatures to be maintained in house (°F.)	Area of glass, at outside temperatures of—					
	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.
	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
40 to 45	7. 57	5. 27	4. 01	3. 23	2. 73	2. 35
45 to 50	5. 92	4. 34	3. 43	2. 84	2. 42	2. 11
50 to 55	4. 83	3. 70	3. 00	2. 52	2. 18	1. 91
55 to 60	4. 08	3. 18	2. 65	2. 27	1. 97	1. 75
60 to 65	3. 46	2. 79	2. 35	2. 03	1. 78	1. 59
65 to 70	2. 98	2. 46	2. 09	1. 82	1. 61	1. 45
70 to 75	2. 54	2. 13	1. 83	1. 61	1. 43	1. 30

[1] The total equivalent glass exposure may be taken as the area of the actual outside glass surface of the house plus one-half the area of the other outer walls, as would be needed for a wooden or a somewhat leaky masonry wall. For tight walls of tile, brick, or concrete, 4 square feet of exposure should require no more radiation than 1 square foot of glass.

The data in this table are suitable for well-constructed tight greenhouses. For old leaky structures and for exposed locations, more might be needed.

TABLE 5.—*Area of glass exposure*[1] *that can be heated, per linear foot of 2-inch gravity hot-water pipe radiation*

Temperatures to be maintained in house (°F.)	Area of glass, at outside temperatures of—					
	20° F.	10° F.	0° F.	− 10°F.	−20° F.	−30° F.
	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
40 to 45	5. 28	3. 68	2. 80	2. 26	1. 91	1. 64
45 to 50	4. 13	3. 03	2. 39	1. 98	1. 69	1. 47
50 to 55	3. 29	2. 52	2. 04	1. 72	1. 48	1. 30
55 to 60	2. 72	2. 12	1. 76	1. 51	1. 31	1. 16
60 to 65	2. 24	1. 82	1. 53	1. 32	1. 16	1. 03
65 to 70	1. 89	1. 56	1. 33	1. 15	1. 02	. 92
70 to 75	1. 63	1. 36	1. 17	1. 03	. 91	. 83

[1] The total equivalent glass exposure may be taken as the area of the actual outside glass surface of the house plus one-half the area of the other outer walls, as would be needed for a wooden or a somewhat leaky masonry wall. For tight walls of tile, brick, or concrete, 4 square feet of exposure should require no more radiation than 1 square foot of glass.

The data in this table are suitable for well-constructed tight greenhouses. For old leaky structures and for exposed locations, more might be needed.

TABLE 6.—*Area of glass exposure*[1] *that can be heated, per linear foot of 3½-inch gravity hot-water pipe radiation*

Temperatures to be maintained in house (° F.)	Area of glass, at outside temperatures of—					
	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.
	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
40 to 45	8.60	5.97	4.56	3.68	3.10	2.67
45 to 50	6.66	4.88	3.87	3.20	2.73	2.37
50 to 55	5.33	4.08	3.31	2.78	2.39	2.11
55 to 60	4.32	3.38	2.81	2.41	2.08	1.85
60 to 65	3.60	2.92	2.45	2.12	1.85	1.65
65 to 70	3.00	2.48	2.10	1.82	1.62	1.46
70 to 75	2.56	2.14	1.84	1.62	1.44	1.31

[1] The total equivalent glass exposure may be taken as the area of the actual outside glass surface of the house plus one-half the area of the other outer walls, as would be needed for a wooden or a somewhat leaky masonry wall. For tight walls of tile, brick, or concrete, 4 square feet of exposure should require no more radiation than 1 square foot of glass.

The data in this table are suitable for well-constructed tight greenhouses. For old leaky structures and for exposed locations more might be needed.

TABLE 7.—*Area of glass exposure*[1] *that can be heated, per linear foot of 2-inch forced circulation hot-water pipe radiation*

Temperatures to be maintained in house (° F.)	Area of glass, at outside temperatures of—					
	20° F.	10° F.	0° F.	−10° F.	−20° F.	−30° F.
	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
40 to 45	8.34	5.80	4.42	3.57	3.00	2.58
45 to 50	6.54	4.78	3.79	3.13	2.67	2.33
50 to 55	5.28	4.05	3.28	2.77	2.38	2.09
55 to 60	4.40	3.43	2.86	2.45	2.12	1.88
60 to 65	3.70	2.98	2.52	2.17	1.91	1.70
65 to 70	3.20	2.64	2.24	1.95	1.73	1.55
70 to 75	2.77	2.32	1.99	1.75	1.55	1.41

[1] The total equivalent glass exposure may be taken as the area of the actual outside glass surface of the house plus one-half the area of the other outer walls, as would be needed for a wooden or a somewhat leaky masonry wall. For tight walls of tile, brick, or concrete, 4 square feet of exposure should require no more radiation than 1 square foot of glass.

The data in this table are suitable for well-constructed tight greenhouses. For old leaky structures and for exposed locations more might be needed.

In a rose house that has 6,984 square feet of glass surface and 453 square feet of other wall surface a temperature of 55° to 60° F. is to be maintained against a minimum outside temperature of 0° by a gravity-return low-pressure steam-heating system. The equivalent glass exposure, then, will be

$$6{,}984+\frac{453}{2}=7{,}211 \text{ square feet}$$

Table 4 shows, for inside and outside temperatures as stated, that 1 linear foot of 1¼-inch pipe will heat 2.65 square feet of glass. Therefore the length of 1¼-inch pipe required for radiation will be

$$7{,}211\div 2.65=2{,}720 \text{ feet}$$

If the heat were to be supplied by a forced-circulation hot-water system with 2-inch pipe, the glass area heated would be 2.86 square feet per linear foot of pipe, as shown in Table 7, and the length of pipe would be

$$7{,}211 \div 2.86 = 2{,}520 \text{ feet}$$

The quantities of glass surface per foot of pipe shown in Tables 4 to 7 are designed to maintain the inside temperatures specified under all but extreme conditions of temperature and wind. During periods of high wind it is difficult to heat a greenhouse, especially when the outside temperature is such that there is no sealing of the cracks by frozen moisture of condensation.

Table 4 calls for slightly more radiation than is commonly used where there is constant attention to the plant. Usually the crop to be grown will stand a few degrees drop in temperature during periods of severe cold or wind. If this is the case, the next larger ratio of glass exposure may be used and the cost of the plant correspondingly reduced. For instance, if it is desired to maintain a temperature of 60° F. in a house, but the crop will not be injured by a temperature slightly below 55° for brief periods, expense will be saved by basing the design on 55°, yet the plant will maintain 60° under even moderately severe conditions. The minimum allowable temperature to select must be left to the judgment of the owner. It is wise in a general-purpose greenhouse, such as a retail florist's plant, to install piping sufficient to maintain a temperature 5° to 10° higher than the immediate purpose requires, with sufficient valve control to permit operation at such lower temperatures as may be desired. This will permit changing crops at will, or operating for short periods, as when forcing, at high temperatures.

Boiler ratings often are given in terms of equivalent cast-iron radiation that can be supplied when standing in air at 70° F., and it is frequently necessary to convert from the linear feet of pipe-coil radiation to the equivalent cast-iron standing radiation. Table 8 gives the data for making such conversions. For example, cast-iron standing radiation equivalent of 3,000 linear feet of 2-inch gravity-circulation hot-water piping when surrounded by air at 55° to 60° is three times 817 square feet (Table 8), or 2,451 square feet in air at 70°.

TABLE 8.—*Cast-iron standing radiation, in air at 70° F., equivalent in heat emission to 1,000 linear feet of pipe radiation of kinds specified in air at indicated greenhouse temperature*[1]

Type and size of pipe radiation	Equivalent cast-iron standing radiation, at house temperatures of—						
	40°–45° F.	45°–50° F.	50°–55° F.	55°–60° F.	60°–65° F.	65°–70° F.	70°–75° F.
	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
Low-pressure steam, 1¼-inch	750	721	693	665	640	613	588
Hot-water open system gravity circulation, 2-inch	961	918	866	817	774	728	684
Hot-water pump circulation, 2-inch	1,515	1,456	1,392	1,329	1,277	1,221	1,168
Hot-water open system gravity circulation, 3½-inch	1,568	1,487	1,406	1,306	1,235	1,164	1,087

[1] 1 boiler horsepower is approximately equivalent to 100 square feet of cast-iron steam radiation in air at 70° F., or to 160 square feet of cast-iron water radiation.

STEAM-PIPE SIZES

The principal factors upon which the sizes of pipe in steam heating depends are (1) the equivalent length of run from the boiler or source of supply to the farthest radiator, (2) the total allowable pressure drop between the source of supply and the farthest radiator, and (3) the maximum allowable velocity of steam commensurate with quiet and satisfactory operation of the system.

The length of run must not only include the linear measured distance along the pipe, but also allow for the effect of fittings, valves, bends, etc. Table 9 gives the equivalent lengths of pipe for various kinds and sizes of fittings to be added to the actual length of run in order to obtain the equivalent total length.

TABLE 9.—*Lengths to be added to actual length of run of steam pipe to obtain equivalent length*

Size of pipe (inches)	Length to be added to actual run for each—					Size of pipe (inches)	Length to be added to actual run for each—				
	Standard elbow	Side outlet T	Gate valve	Globe valve	Angle valve		Standard elbow	Side outlet T	Gate valve	Globe valve	Angle valve
	Feet	*Feet*	*Feet*	*Feet*	*Feet*		*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
2	5	16	2	18	9	7	26	55	10	82	37
3½	7	20	3	25	12	8	31	63	12	94	42
3	10	26	3	33	16	9	35	69	13	105	47
½	12	31	4	39	19	10	39	76	15	118	52
4	14	35	5	45	22	12	47	90	18	140	63
5	18	44	7	57	28	14	53	105	20	160	72
6	22	50	9	70	32						

The factors to be considered in determining allowable pressure drop are the initial pressure; the pressure required at the end of the steam line; the variations in the initial pressure; the vertical distance between the low point of dry return and the boiler-water line, where the return of condensate to boiler is by gravity; and any extra tax on the system during heating-up periods. With a high initial pressure it is possible to allow a large drop if there is sufficient difference in elevation between the low point of dry return and the water line of the boiler. It is advisable to design systems for relatively low pressure drops and for satisfactory operation under the lowest steam pressure that may prevail.

The capacity of a pipe of given size in any part of a steam system depends on the quantity of condensed water in the pipe as well as upon the allowable pressure drop through the pipe. Where no appreciable water is present or where the water and steam travel in the same direction, only the pressure drop is of importance. Where water and steam flow counter to each other in the same pipe, the velocity of the steam must be maintained below a certain value in order that "water hammer" and the storage of water in parts of the system may not occur.

Table 10 gives the linear feet of 1¼-inch pipe radiation which can be served by 100 feet of new clean steam pipes at various rates

of pressure drop and from an initial gauge pressure of 1 pound per square inch. If the equivalent length of pipe is other than 100 feet, the capacity will be determined from the table by first computing the rate of pressure drop per 100 feet. The lengths to be added to actual lengths of run to obtain the equivalent length are given in Table 9.

TABLE 10.—*Length of 1¼-inch pipe radiation to be served by 100 feet of new clean steam pipes from an initial gauge pressure of 1 pound per square inch*[1]

Pressure drop per 100 feet (ounces)	Length of 1¼-inch pipe radiation served by—									
	1-inch pipe	1½-inch pipe	2-inch pipe	3-inch pipe	4-inch pipe	5-inch pipe	6-inch pipe	8-inch pipe	10-inch pipe	12-inch pipe
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
¼	42	143	290	872	1, 844	3, 410	5, 597	11, 649	21, 258	34, 119
½	59	201	410	1, 233	2, 607	4, 821	7, 914	16, 475	30, 065	48, 252
1	84	285	579	1, 745	3, 696	6, 819	11, 193	23, 300	42, 518	68, 233
2	119	404	819	2, 468	5, 213	9, 644	15, 830	32, 951	60, 128	96, 504
4	167	570	1, 157	3, 489	7, 371	13, 638	22, 386	46, 600	85, 034	136, 478
6	204	699	1, 418	4, 272	9, 029	16, 703	27, 417	57, 072	104, 145	167, 150
8	235	807	1, 637	4, 934	10, 425	19, 287	31, 658	65, 901	120, 257	192, 998
10	264	901	1, 830	5, 516	11, 655	21, 564	35, 396	73, 680	134, 450	215, 790
12	288	989	2, 004	6, 042	12, 768	23, 622	38, 774	80, 712	147, 282	236, 385
16	335	1, 140	2, 315	6, 977	14, 744	27, 276	44, 772	93, 198	170, 067	272, 954
20	374	1, 275	2, 709	7, 800	16, 484	30, 497	50, 057	104, 199	190, 052	305, 172
24	410	1, 397	2, 835	8, 546	18, 057	33, 405	54, 824	114, 144	208, 289	334, 299

[1] Based on data from the American Society of Heating and Ventilating Engineers' Guide for 1932.

The use of Table 10 is illustrated in determining the capacity of 200 feet of 2-inch pipe with 1 pound initial pressure and 4 ounces pressure drop in the 200-foot run. A pressure drop of 4 ounces in 200 feet is equivalent to a 2-ounce drop in 100 feet, for which Table 10 shows that the capacity of 100 feet of 2-inch piping is 819 feet of 1¼-inch radiation. This is, therefore, the capacity of the 200 feet of 2-inch piping with a drop of 4 ounces.

Conversely, if the load, total pressure drop, and length of run are known the size of pipe can be determined from Table 10 when the initial pressure is 1 pound per square inch. For example, if the radiation load is 546 linear feet of 1¼-inch pipe and the pressure drop is not to exceed 4 ounces in the run of 200 feet, what size of pipe shall be used? The limiting pressure drop is equivalent to 2 ounces drop in 100 feet, for which the table shows that, while 2-inch pipe has more capacity than is required, 1½-inch pipe is not large enough.

If the initial pressure should be other than 1 pound per square inch, a coefficient should be applied to the radiation capacities shown in Table 10, such coefficients being shown below. Thus, if the initial pressure were 5 pounds per square inch, the quantities in Table 10 would be multiplied by 1.11, and for the preceding example 546 feet of radiation would have been compared with 448 and 909 feet instead of with 404 and 819 feet. Or it may be more convenient to divide the given amount of radiation (546 in the preceding example) by the same coefficient and compare directly with the lengths shown in Table 10.

Initial pressure (steam gauge) Pounds per square inch:	Coefficient for pressure	Initial pressure (steam gauge) Pounds per square inch:	Coefficient for pressure
0	0.92	50	1.94
1	1.00	60	2.08
2	1.03	75	2.26
5	1.11	100	2.54
10	1.24	125	2.79
15	1.35	150	3.02
20	1.45	175	3.23
30	1.63	200	3.44
40	1.79		

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For proportioning the piping and valves in any low-pressure steam system in which the maximum equivalent length of piping from boiler to farthest radiator is not over 600 feet and the total pressure drop between boiler and farthest radiator is to be 4 ounces, using Table 11 will be found more convenient than computing from Table 10 and the above tabulation.

TABLE 11.—*Length of 1¼-inch pipe radiation to be served by new clean steam pipes and by radiator valves, in low-pressure gravity steam-heating systems, with total pressure drop of 4 ounces* [1]

Pipe size of main or valve (inches)	Length of 1¼-inch pipe radiation served by—													
	Supply main [2] having equivalent length [3] of—						Return main [2] having equivalent length [3] of—						Radiator valves	
	100	200	300	400	500	600	100	200	300	400	500	600	Supply	Return
	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet
¾	------	------	------	------	------	------	------	------	------	------	------	------	45	183
1	167	119	98	84	74	69	690	618	552	480	483	413	84	285
1¼	368	260	212	183	165	150	1,443	1,302	1,155	1,005	869	720	183	580
1½	570	404	330	285	248	233	2,268	2,043	1,815	1,587	1,364	1,136	285	953
2	1,157	819	669	579	518	473	4,950	4,440	3,960	3,450	2,970	2,445	580	------
2½	1,905	1,347	1,101	953	852	777	7,175	8,350	6,570	5,700	4,950	4,155	953	------
3	3,489	2,468	2,013	1,745	1,560	1,422	15,000	13,500	12,000	10,500	9,000	7,500	------	------
3½	5,211	3,686	3,009	2,606	2,328	2,129	21,450	19,350	17,250	15,000	12,900	10,800	------	------
4	7,371	5,213	4,242	3,686	3,294	3,017	32.250	28,950	25,800	22,500	19,350	16,050	------	------
5	13,638	9,644	7,875	6,819	6,093	5,562	------	------	------	------	------	------	------	------
6	22,386	15,830	12,927	11,193	10,000	9,141	------	------	------	------	------	------	------	------
8	46,600	32,957	26,903	23,300	20,820	19,023	------	------	------	------	------	------	------	------
10	85,034	60,128	49,095	42,518	38,000	34,716	------	------	------	------	------	------	------	------
12	136,478	96,504	78,795	68,238	60,990	55,718	------	------	------	------	------	------	------	------

[1] Based on data from the American Society of Heating and Ventilating Engineers' Guide, 1932.
[2] Pipes are assumed to be reamed, supply mains dripped, and steam and condensate flowing in same direction. When steam and condensate flow in opposite directions, pipe should be next larger size.
[3] From boiler to farthest radiator.

For the proportioning of vapor and vacuum systems, Tables 10 and 11 hold for the design of supply mains, supply risers, and branches. Different makes of supply and return valves, steam traps, and other specialties vary as to capacity, so the recommendations of the manufacturer of the particular fittings to be used should be followed.

For the design of small 2-pipe steam heating systems, such as those in which the equivalent lengths of supply and return mains are less than 200 feet, the capacities for supply and return mains

as given in Table 12 are generally used by greenhouse heating specialists. These values are based on somewhat lower total pressure drops than those used for Tables 10 and 11, perhaps on the assumption that the smaller plants generally do not have as constant attendance as do the larger plants and consequently their boiler pressures would probably fall below that required by the greater pressure drops.

TABLE 12.—*Length of 1¼-inch pipe radiation to be served by new clean pipes in low-pressure gravity steam-heating system where equivalent length of run from boiler to farthest radiator does not exceed 200 feet* [1]

Pipe size (inches)	Supply main	Return main	Pipe size (inches)	Supply main	Return main
	Feet	*Feet*		*Feet*	*Feet*
1	84	480	3	1,740	10,500
1¼	183	1,007	3½	2,610	15,000
1½	285	1,587	4	3,680	
2	577	3,450	5	6,820	
2½	953	5,680	6	11,200	

[1] Based on data from the American Society of Heating and Ventilating Engineers' Guide for 1932.

Mains and radiation coils are generally pitched not less than 1 inch in 20 feet, to cause the condensate to flow. When the pipe is pitched so that the condensate flows contrary to the direction of steam flow, it is well to use one size larger than those given in the tables.

The water in the returns of a gravity-circulation system is carried enough higher than the boiler-water level to force the water into the boiler, allowing for friction in the piping and the resistance of the check valve. At any given steam pressure the friction loss depends principally on the size of pipe and the quantity of steam flowing. To allow for the necessary elevation in the returns there must be adequate clearance between the lowest point of the heating coils and the boiler-water line. A minimum water-line difference of 3 feet should be allowed for a 4-ounce pressure drop between the boiler and the farthest radiator, and 4 to 6 inches additional difference for each additional ounce of pressure drop. This provision will allow the water to back up in the risers without entering the steam main or radiation. For piping designed for a 4-ounce pressure drop, as in Table 11, a clearance of 3 feet should be adequate.

BOILERS

Boilers used for greenhouse heating are similar to those employed for heating other types of structures. However, heating-boiler ratings are ordinarily given either in terms of square feet of direct radiation that can be supplied or of horsepower output, while the greenhouse-boiler manufacturer rates his product, whether of the steam or the water type, in terms of linear feet of pipe radiation of specified size. This is a convenient method of rating and obviates the necessity for converting from one unit to another.

For very small greenhouses, conservatories, and heated frames small round boilers are made by manufacturers of greenhouse heating equipment. The capacities vary according to the diameter of the

boiler and the number of sections. For somewhat larger greenhouses the boiler types employed in residence heating are used. Such heaters are rugged and give good service over long periods with minimum expenditures for repairs. They are generally limited in capacity to about 2,000 linear feet of 1¼-inch pipe radiation.

For still larger greenhouses rectangular cast-iron boilers of the sectional type are common; these are rated as high as several thousand feet of 1¼-inch pipe radiation. This type of boiler can be increased in capacity by adding sections, as in the case of the round boiler. When sections are added to a rectangular sectional boiler, however, the grate area, combustion volume, and direct heating surface are increased as well as the indirect heating surface. This is advantageous when altering a boiler to adapt it to oil burning. It is sometimes assumed that the small round boilers are inherently inefficient as compared with the square sectional type. This, however, is not true if they are used within the proper limit of their capacity. Cast-iron boilers may be used with either steam or hot-water heating systems though they require different gauges and other accessories.

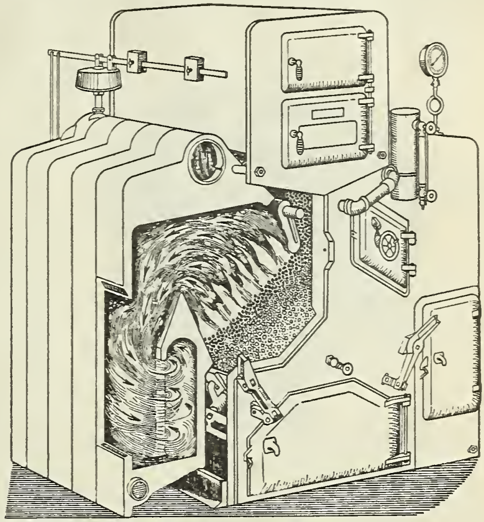

FIGURE 15.—Cast-iron magazine-feed boiler

A magazine-feed type of cast-iron boiler well suited to greenhouse heating is shown in Figure 15. Comparatively large quantities of a cheap grade of coal are placed in the magazine and fed by gravity as the fuel on the grate is consumed, thus increasing the length of time that the fire will burn without attention. Magazine-feed boilers are also built in the larger steel tubular form shown in Figure 16, and in this form may have a capacity as large as 100 horsepower in a single unit. Where this type of boiler is used, particular attention should be given to the recommendations of the manufacturer as to the stack, because the draft requirements may be somewhat different from those of the ordinary flat-grate boiler.

Boilers for very large greenhouse installations are of steel construction and comprise three types—fire tube, water tube, and combined fire-and-water tube. The fire-tube boiler usually employed is of the horizontal return tubular form. This is not generally built in units of over 200-horsepower capacity. The Scotch marine boiler, another of the fire-tube type, is frequently installed in greenhouses. It has the advantage that no brick setting is required, and consequently there is no danger of air leakage and accompanying loss of efficiency. For the proper burning of bituminous coals the furnaces and combustion chambers of such boilers should be liberal in size.

The water-tube boiler is the type toward which modern power-plant practice tends. In general, these boilers are of two classes—those having straight tubes and those having bent tubes.

The straight-tube boiler is made in both horizontal and vertical forms. In the horizontal form the tubes are arranged horizontally or slightly inclined from the horizontal. As a rule this form of water-tube boiler has a large number of handhole plates in the headers which must be removed when tubes are inspected and cleaned. These must be replaced carefully to prevent leakage. In the vertical form the tubes are approximately vertical. Few vertical straight-tube boilers have either handhole plates or headers, the tubes being fastened directly into the drums. The absence of handhole plates obviates the danger of leaky joints. Such boilers are adapted to both coal firing by stoker and to the burning of oil.

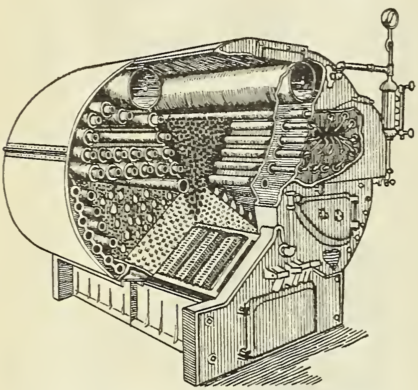

FIGURE 16.—Steel tubular magazine-feed boiler

The bent-tube boiler is of the vertical form. The tubes are secured directly to the drum; no headers are used and hence no handhole plates are necessary. Being bent, the tubes are not so easy to inspect and clean, and defective tubes are not so easily removed, as are those of a straight-tube boiler. Because the tubes are not all alike, more spare tubes must be kept on hand for repairs.

A combination fire-and-water tube boiler usually consists of a fire-tube boiler mounted upon steel headers to which are secured one or more rows of water tubes. It is claimed that this kind of boiler combines the advantages of the large storage capacity characteristic of the horizontal return-tubular boiler with those of the thorough circulation and rapid steaming properties of the water-tube boiler.

In practice the ratings for steam boilers when hand fired are based on varying quantities of fuel burned per square foot of grate area, depending upon the size of the boiler. Thus the rated capacities of the smaller cast-iron boilers attached to stacks of the sizes recommended by the manufacturers are apparently based on the assumption that approximately 6 pounds of coal will be consumed per square foot of grate surface per hour. For the larger steel boilers, hand fired, the fuel burned per square foot of grate is assumed to be approximately 20 pounds. Figure 17 shows the relation between the quantity of coal burned per hour and the area of grate surface for the ordinary hand-fired boiler used for greenhouse heating. The performance indicated is obtainable only when the size of stack recommended by the boiler manufacturer is used. If stacks of sufficient size were attached to the smaller boilers, the combustion rates could be boosted to 15 or 20 pounds per square foot of grate surface per hour. Such is not done in practice, however, and the heat-absorbing surfaces are proportioned for the lower combustion rates. The capacity of any boiler may be increased by mechanical stokers.

The curves of Figure 18 show the grate area required by a single-boiler unit to supply the heat necessary to maintain given temperatures under the designated areas of glass. To provide for loss in piping and for added boiler capacity to care for rapid changes in load, 20 to 25 per cent should be added to grate areas as determined from Figure 18. Any stand-by capacity required for emergency operation, as in case of breakdown or when cleaning is necessary, must be provided in addition.

The number and the sizes of boilers that should be installed for a large greenhouse will depend principally upon the size of the plant, the maximum steam demand that may occur, and the capacity at which the boilers must be operated for maximum economy. The boiler units should be as large as is consistent with the capacity of the plant and the desired flexibility. At times it is necessary to shut down in order to clean boilers or repair settings, so it is important to provide enough extra units for such contingencies.

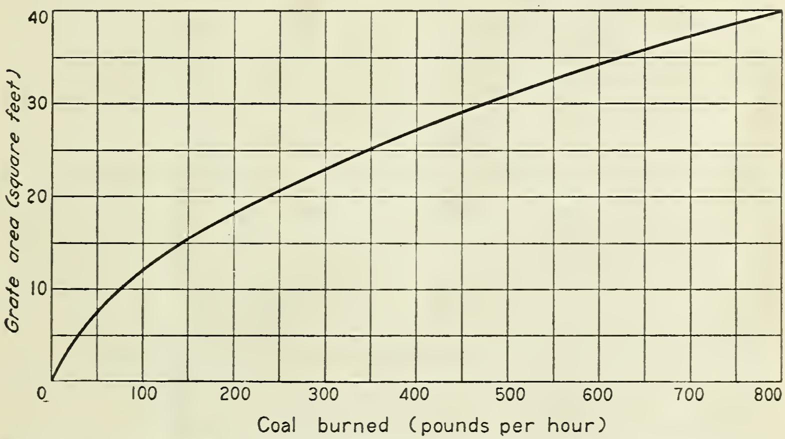

FIGURE 17.—Quantities of coal burned hourly by typical hand-fired greenhouse heating boilers of various grate sizes

In many greenhouses provision must be made for the generation of steam for soil sterilization. If the heating system is of the hot-water type, this can be done by providing the boilers with injectors or pumps for supplying water and with headers for collecting steam, as well as with suitable gauges, safety valves, and other accessories to permit safe use for this purpose.

CHIMNEYS

Chimneys are generally constructed of steel, common brick, radial brick, reinforced concrete, or tile with reinforced concrete. Occasionally the chimney is connected with the wall of the building, in which case the lower portion is constructed of the same material as is used in the wall.

The larger steel chimneys, as a rule, are lined with fire brick. Sometimes the fire-brick lining extends only a limited distance above the breeching, common brick being used for the remainder of the height where the temperatures are somewhat lower. In the better types the brick lining is separated from the steel about 1 inch, the

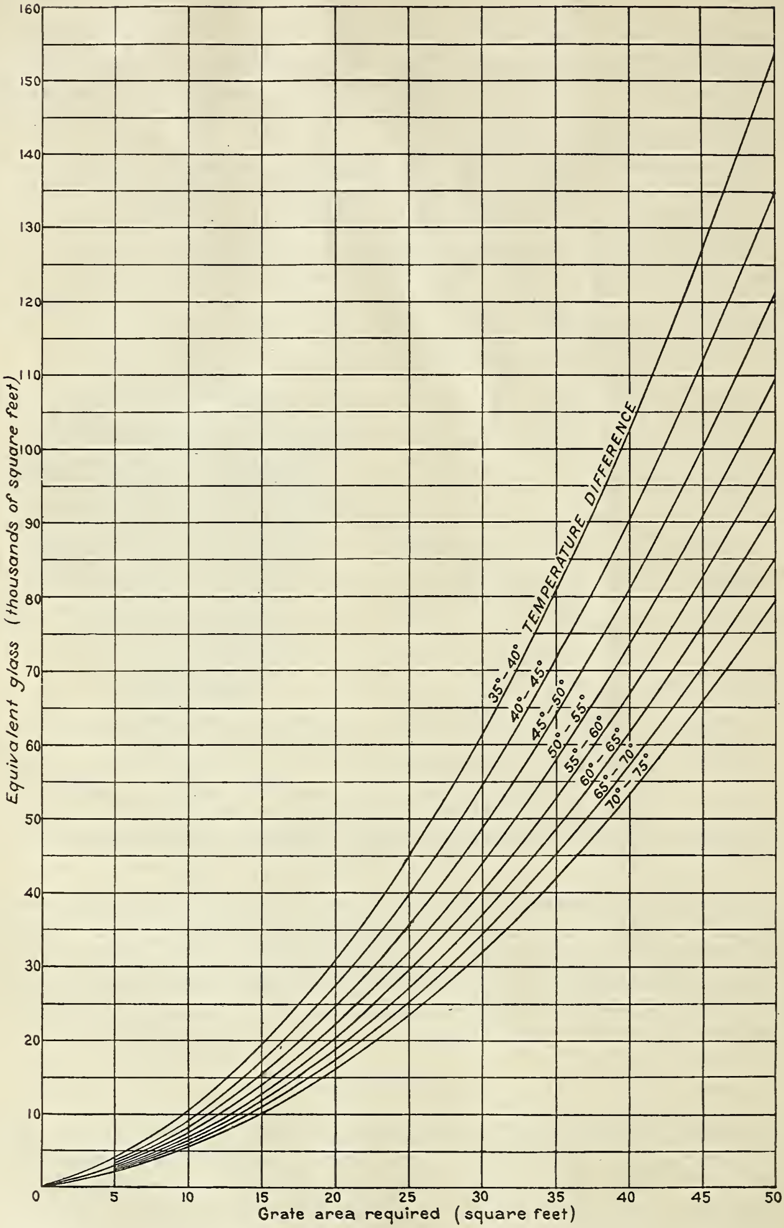

FIGURE 18.—Relation between the grate area required and the equivalent glass area for various greenhouse temperatures (based on Table 2, assuming boiler efficiency 70 per cent and calorific value of coal 13,000 British thermal units per pound)

space being filled with cement grout. This construction increases the life of the chimney.

The use of radial brick has almost entirely superseded that of common brick in the construction of modern power-plant chimneys. Radial brick are perforated vertically with square holes, and in making the joints mortar is worked into these to trap air and thus improve the insulating properties and decrease the temperature drop of the gases in the stack. The radial-brick chimney has greater strength than a common-brick chimney of the same weight. It is lined like the steel type.

Concrete chimneys are reinforced with heavy vertical rods and lighter circumferential hoops or steel mesh and lined with brick. Reinforced tile-concrete construction has also been used with considerable success. The tiles are made of fire clay and serve as permanent forms for the concrete. The concrete filling between the shells of the tile is reinforced with steel, both vertically and circumferentially.

Most chimneys are round. The sizes given in Table 13 have been computed with a commonly used design formula proposed by Kent.[7] The boiler capacities given in the table are conservative, being based on a comparatively low boiler efficiency. The height of a chimney depends upon the draft requirements of the particular boiler used; therefore these factors must be known before a reliable estimate of the height can be made. The figures in the table, which hold for the average hand-fired coal-burning boiler, should be considered as only sufficiently accurate for making preliminary estimates.

TABLE 13.—*Chimney dimensions for hand-fired coal-burning boilers*[1]

Inside diameter of round chimney (inches)	Side of equivalent square chimney	Actual area	Commercial ratings[2] of boilers adapted to chimney heights of—							
			50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	110 feet	125 feet
	Inches	*Square feet*	*Horse-power*	*Horse-power*	*Horse-power*	*Horse-power*	*Horse-power*	*Horse-power*	*Horse-power*	*Horse-power*
18	16	1.77	23	25	27	29				
21	19	2.41	35	38	41	44				
24	22	3.14	49	54	58	62	66			
27	24	3.98	65	72	78	83	88			
30	27	4.91	84	92	100	107	113	119		
33	30	5.94		115	125	133	141	149	156	
36	32	7.07		141	152	163	173	182	191	204
39	35	8.30			183	196	208	219	229	245
42	38	9.62			216	231	245	258	271	289
48	43	12.57				311	330	348	365	389
54	48	15.90					427	449	472	503
60	54	19.64					536	565	593	632
66	59	23.76						694	728	776
72	64	28.27						835	876	934
78	70	33.18							1,038	1,107
84	75	38.48							1,214	1,294
90	80	44.18								1,496
96	86	50.27								1,712
102	91	56.75								1,944
108	96	63.62								2,090

[1] Reprinted from the tenth edition of Kent's Mechanical Engineers' Handbook, by permission.
[2] These relations are only approximate and should in no case be given preference over recommendations of reliable boiler or stoker manufacturers.

The chimney dimensions given in Table 13 are for boilers of 23-horsepower or greater capacity. Table 14 gives the sizes of

[7] KENT, R. T. KENT'S MECHANICAL ENGINEERS' HANDBOOK. Ed. 10, rewritten . . ., 2247 p., illus. New York and London.

chimneys ordinarily provided for boilers having from 2 to 10 square feet of grate area, in accordance with common practice for small greenhouses. These sizes have proved satisfactory for average flat-grate cast-iron boilers under normal conditions of operation. Manufacturers ordinarily will not guarantee the performance of their boilers unless the chimneys meet specified requirements which they have found to be essential. Hence the manufacturer's recommendation should be followed in preference to the dimensions indicated in Table 14 in case the two do not agree.

TABLE 14.—*Sizes of flue linings and heights of chimneys recommended for flat-grate cast-iron boilers burning bituminous coal*[1]

Grate area (square feet)	Size of chimney flue lining[2]		Height of chimney above grate	Grate area (square feet)	Size of chimney flue lining[2]		Height of chimney above grate
	Round	Rectangular			Round	Rectangular	
	Inches	*Inches*	*Feet*		*Inches*	*Inches*	*Feet*
2	11¾	8½ by 13	24	7	20½	20 by 20	32
3	13	13 by 13	26	8	20½	20 by 20	35
4	13	13 by 13	30	9	20½	20 by 20	38
5	13	13 by 13	32	10	20½	20 by 20	40
6	17¼	18 by 18	30				

[1] For anthracite-coal installations the area of the chimney may be reduced about 25 per cent.
[2] Approximate outside dimensions of commercial flue linings.

DESIGN OF HEATING SYSTEMS[8]

Use of the design data in the foregoing tables is best illustrated by working out plants for representative installations.

STEAM HEATING PLANT

For this illustration a low-pressure steam heating system will be designed for the greenhouse represented in Figure 19. The house is to be located in a region where the lowest recorded temperature is approximately 0° F., therefore the design is based on an outside temperature of 10°, and it is desired to maintain a temperature of 50° to 55° inside. The boiler is to be placed in a cellar under the head house. All radiation will be placed on walls, due to type of crop to be grown.

The greenhouse is 100 feet long and 25 feet wide, and the equivalent exposed glass surface is approximately 5,450 square feet. Under the conditions stated, Table 4 shows that 1 linear foot of 1¼-inch pipe will adequately heat 3.7 square feet of glass. Therefore, 1,470 linear feet of such pipe radiation are required. A bank of six pipes along the side walls and at the exposed end of the greenhouse will provide almost all the radiation required. The return line, shown below the row of heating pipes proper, will provide approximately the additional 150 feet required.

Proper determination of the size of boiler is very important and should receive careful consideration. Figure 18 gives the relation

[8] For information on insulation of mains see American Society of Heating and Ventilating Engineers' Guide; also handbooks issued by manufacturers of insulating materials.

between grate area and area of glass for various differences between the greenhouse and outside temperatures. In this example the temperature difference is 40° to 45°, for which Figure 18 shows the required grate area to be about 7.25 square feet. This result may be checked against the recommendations of boiler manufacturers for the equivalent load in terms of square feet of cast-iron radiation. According to the catalogue ratings of one well-known manufacturer, the proper size boiler for the proposed installation would have 7.26 square feet of grate area, while another manufacturer recommends 7.12 square feet of grate area.

One of the most important factors of design in connection with a boiler is the stack size. From Table 14 it is seen that a boiler having 7.25 square feet of grate, when burning soft coal, will require a stack such as would be built with a 20½-inch round or 20-inch square flue lining (outside measurement), and about 32 feet high. However, as previously stated, in any case of disagreement between the results obtained from Table 13 or 14 and the recommendation of the boiler manufacturer, the latter should be given preference.

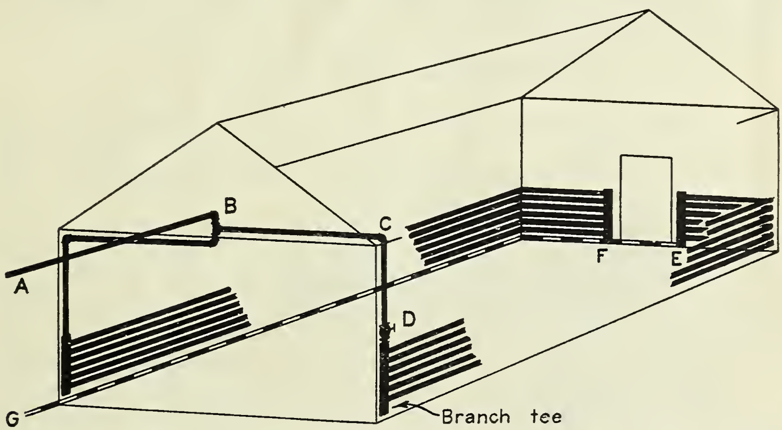

FIGURE 19.—Layout of boiler, piping, and radiation for low-pressure steam heating of a small greenhouse

Table 12 can now be employed to design the supply and return piping and radiator supply and return valves. Beginning at the boiler the supply main sizes can be determined as follows: From A to B (fig. 19) the main carries all the steam required for the total radiation of 1,470 feet of 1¼-inch pipe. Table 12 shows that this amount of radiation requires a pipe size between 2½ and 3 inches. The larger size should be selected. Accordingly, the main supply line from A to B will be 3 inches.

The size of the branch from B to D would next be determined. One-half of the total steam flowing will pass through this branch, and one-half through the similar pipe that supplies steam to the radiation on the opposite wall. Since this is a short line, about 20 feet long, it should be the same as the radiator supply valve size given in Table 11 under the appropriate column, or 2½ inches.

In determining the sizes of the return main from E to F and from F to G, capacity must be provided for the condensate from the

second radiator which is discharged into the return line at point F. The line from E to F carries the condensate from one-half the total radiation in the house—that is, from 735 linear feet of 1¼-inch pipe—for which Table 12 shows that a 1¼-inch return main will be adequate. From F to G the condensate from the entire 1,470 linear feet of 1¼-inch pipe is to be carried, therefore a 1½-inch return line will be required. The recommendation of Table 11 is for a 1½-inch radiator valve on the return end of each unit of radiation on the side walls.

It is of importance to provide adequately for expansion of the heating coils in a steam system such as the one being designed. When steam is admitted to a bank of coils it is probable that at first there will be large differences in temperature in the several lines. Provision for the consequent inequality of expansion of the several lines must be made in order to prevent the breaking of the cast-iron headers or branch tees. This is done by turning the corners at the end of the house with the radiation pipes, as shown in Figure 19.

HOT-WATER HEATING PLANT

The design of piping systems for hot-water heating is somewhat more complex than for steam heating. For a given combination of circumstances any one of several arrangements may operate satisfactorily.

The pressure head which tends to make the water flow through the system depends largely upon the height of the radiation above the boilers, and the effectiveness of this difference in level depends largely upon the arrangement of the supply and return mains. The use of overhead mains produces a stronger circulation of the water, but since they are near the glass they are relatively less effective for heating than lower lines; also, the practice of passing all the water to the far end of the house in the supply mains and then bringing it forward in the radiation lines produced uneven heating of the house.

The minimum depth at which the boiler must be placed in order to produce the desired circulation depends chiefly upon the arrangement of the supply mains. The lower the boiler the greater the available head for circulation, but the cost of excavation or the height of ground water may limit the depth at which the boiler is placed. Greenhouse-heating specialists have adopted the rule that for an overhead feed system with flow mains approximately 6 to 8 feet above the radiation pipes the return tappings of the boiler must be at least 3 feet below the radiation lines. In a so-called up-feed system (fig. 20), however, where the supply main is at about the same height as the radiation, the boiler should be set lower, so that its top will be at least 3 feet below the radiating lines. This requires a depth of cellar of about 8 feet for an ordinary cast-iron boiler. The figures given in Table 15 should prove satisfactory in proportioning the mains for heating systems in which the boilers are placed in accordance with these specifications.

TABLE 15.—*Length of gravity-circulation hot-water radiation to be served by new clean mains with ends reamed, when combined length of supply and return mains does not exceed 200 feet*

Size of main (inches)	Length of radiation pipe of—		Size of main (inches)	Length of radiation pipe of—	
	3½-inch diameter	2-inch diameter		3½-inch diameter	2-inch diameter
	Feet	*Feet*		*Feet*	*Feet*
1¼	50	80	3½	1,000	1,700
1½	80	140	4	1,500	2,600
2	190	320	5	3,000	5,000
2½	380	650	6	5,200	8,700
3	660	1,100			

Where it is not practicable to place the boiler quite so low as is required by the above rule, it is well to increase the sizes of the supply and return mains, and in extreme cases where the boiler is located on practically the same level as the radiation lines a mechanical flow accelerator can be employed advantageously. The more simple of these accelerators are electric-motor driven, and therefore can be used only where electric current is available. The laying out of a large forced-circulation hot-water plant is an engineering problem which must be handled by a competent heating engineer.

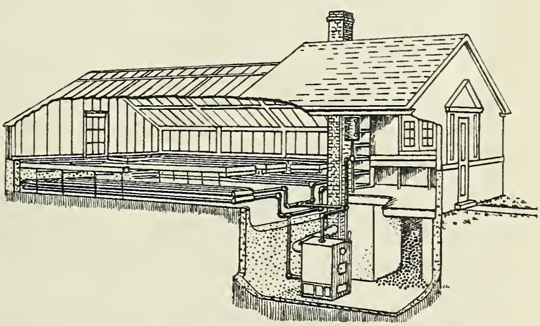

FIGURE 20.—Layout of boiler, piping, and radiation for gravity-flow hot-water heating of a small greenhouse

To illustrate the design of a hot-water heating system for a small greenhouse, a plant may be worked out for the house illustrated in Figure 20. The lowest recorded temperature for the region of this house is approximately −10° F., and it is desired to maintain a temperature of 50° to 55° inside. As in the preceding problem, the boiler is to be placed in a cellar under the head house.

The house, about 16 by 32 feet in plan, not including the head house, has an equivalent exposed area of 1,000 square feet of glass surface. It is desired to determine the amount of 2-inch pipe required to heat this structure when utilizing a gravity-flow hot-water heating system, together with the sizes of supply and return mains for the radiation. The selection of boiler and stack as described in the preceding illustration is not repeated.

From Table 5 it is seen that 1 linear foot of 2-inch pipe when used with a gravity-flow hot-water heating system will adequately heat 2.04 square feet of glass when the outside temperature is 0° F., or 10° above the lowest recorded temperature of the locality. Therefore, 490 linear feet (1,000÷2.04) of 2-inch pipe radiation will be required. If the radiation is installed under the benches adjacent to

the wall, as shown in Figure 20, two sets of coils having an average length of approximately 31 feet and each containing eight pipes will be required, or a total of 248 feet of pipe in each coil. Therefore, in accordance with Table 15, a 2-inch supply line and a 2-inch return line will be required for each coil, while the supply and return mains connected to the boiler and carrying the water for both coils together should be 2½ inches. As previously stated, for use of the data in Table 15 the top of the boiler must be at least 3 feet below the radiation lines.

USE OF OIL FUEL

The convenience and flexibility of oil-fired heating systems are, of course, desirable characteristics for greenhouse heating. On the other hand, there are few industries where continuity of heating service is of greater importance. Failure of a heating system during severe weather may result in total loss of crop. Where oil-fired units are installed, therefore, all possible precaution should be taken to guard against any cessation of service. It is imperative that any oil burner installed shall be handled and serviced by a reliable concern. Oil burners that depend upon electrical energy for their operation are not feasible if there is likelihood of temporary current failure, due to storms or other causes. On the other hand, burners that are independent of electrical energy—by virtue of the use of steam for atomization—generally require some auxiliary device for starting up the plant in the event that the oil fuel drops below atomizing temperature.

Oil burners suitable for greenhouse heating vary in type from the small, full-automatic burner utilizing the lighter distillates to the larger units which are either semiautomatically or manually controlled. Large burners utilize the heavier oil fuels which must be preheated.

With full-automatic-control oil burners the temperature in the greenhouse is maintained constant by means of a thermostat placed at a representative point. The device starts and stops the operation of the burner according to the need for heat in its immediate vicinity. Obviously, therefore, thermostatic control is possible only where the size and other conditions respecting the structure to be heated are such that the temperature actuating the thermostat is representative of that prevailing throughout the structure. The larger burners are generally equipped to maintain a constant pressure or temperature in the supply mains of the heating system, and control of the temperature in the various houses is either manual or by means of one of the devices described under Automatic Controls, page 37.

A true comparison of the costs of heating with oil and with coal involves consideration of not only the costs of fuel but also the costs for labor of operation, repairs and supplies, interest on investment, and depreciation of equipment.

Relative fuel costs have been computed, assuming for coal having a calorific value of 13,000 British thermal units 65 per cent seasonal efficiency when hand fired and 75 per cent seasonal efficiency when stoker fired, and for oil having a calorific value of 150,000 British thermal units per gallon 72 per cent seasonal efficiency. The comparable prices thus computed are shown in Figure 21. Those curves

show, for example, that when coal delivered to a hand-fired plant costs $6.25 per ton of 2,000 pounds the equivalent price of fuel oil would be 4 cents per gallon and when fuel oil costs 5 cents per gallon the equivalent price of coal would be $7.75 per ton. The curves are suitable, it should be understood, only for comparisons relating to the larger size heating plants that burn heavy oil which generally requires preheating.

Selection of the best kind of fuel must be based upon a careful analysis of the final cost of steam making with each. The cheapest fuel may not prove to be the most economical to use. The curves shown in Figure 21 do not tell the whole story, for the entire cost of storing and operating with each fuel must be considered, including

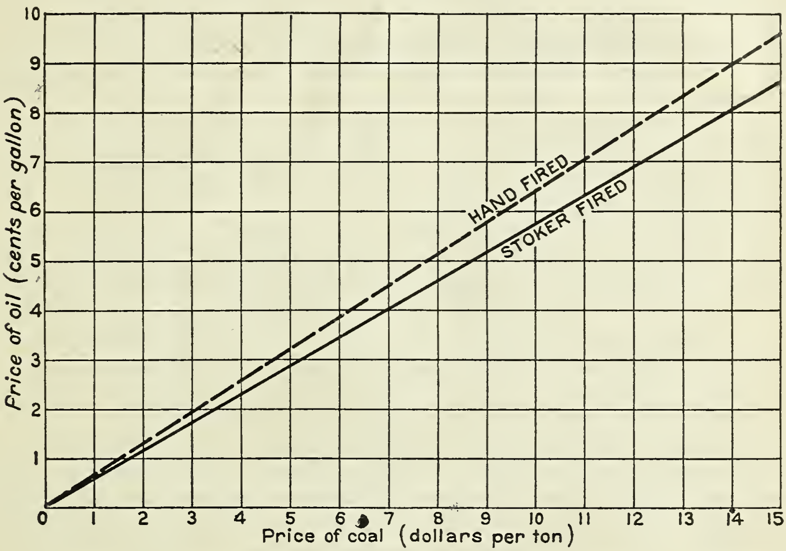

FIGURE 21.—Corresponding prices of oil and coal for equal yearly fuel costs

the fixed charges of interest and depreciation. Still another important factor in considering a given fuel for a plant is the permanence of supply and price. If the item of permanence is not properly considered it may become necessary, after a few years' operation with a given fuel, to shift to some other fuel. In that case the cost of the original plant must be amortized over a short period. However, the present trend undoubtedly is toward use of the cheapest fuel available.

STOKERS

One of the main factors responsible for the high efficiencies of present-day boilers is the development of the mechanical stoker. The increased efficiency due to stokers may be attributed principally to the following characteristics: (1) Fuel is supplied continuously as required, and the use of the fire doors is eliminated, whereby a more uniform temperature is maintained in the furnace, which reduces the stresses in boiler parts due to sudden fluctuations in tem-

perature. (2) Fuel and air quantities can be proportioned as required and altered rapidly to suit the load; less excess air is admitted with stokers than with hand firing.

Three types of stokers in common use are traveling or chain grates, overfeed stokers, and underfeed stokers. In the traveling grate, coal from a hopper flows by gravity onto an endless chain and is ignited as it passes under the ignition arch. Combustion progresses as the fuel is carried toward the rear end of the grate, where the refuse is dumped. Some chain grates use natural draft, others forced draft; in either case the horizontal or the inclined grate may be used. With coals from the Middle West, chain grates are capable of serving boilers up to 200, or even 250 per cent, of the normal rating without excessive smoke. Chain grates are well adapted for burning low-grade free-burning bituminous coal. The speed of the stoker is determined by the time required to completely burn the size and quality of coal used. Forced draft is therefore necessary for obtaining increased rates of combustion on a given size of chain grate. The limit of combustion rate for chain-grate stokers having natural draft and burning Illinois coal is about 40 to 45 pounds of coal per square foot of grate per hour. With forced draft the rate can be maintained at 50 to 60 pounds.

In the overfeed stoker the grates are inclined at an angle of approximately 45°. The coal is fed from a hopper to the top of the grates and is moved gradually toward the lower end by a reciprocating motion of the grates. There are two general types of overfeed stokers, in one of which the coal is fed to the grate from the front end, while in the other type the coal is fed from both sides of a double inclined grate. The overfeed stokers are used for the volatile coals of the Middle West as well as for eastern coal.

In most of the underfeed stokers the fuel is fed from a retort to the underside of the fire by the continuous action of a screw or the intermittent action of a ram. The fire is always on the top, and the fresh coal is fed under the coked and burning coal. Practically all of the underfeed stokers are operated with forced draft. In some types the fuel bed is horizontal, while in others it is inclined. In the latter case gravity aids in distributing the coal and in segregating the refuse at the rear of the stoker. Underfeed stokers carry a thick fuel bed and heavy fire, and because of the use of forced draft they are capable of sustaining high rates of combustion with good efficiency and without smoke. They can burn most varieties of coal and are very well adapted to meeting the demands of sudden loads. They lend themselves easily to automatic control.

The grate surface that must be installed for a boiler of given capacity and a specified fuel is generally based on the amount of heating surface in the boiler. Tables of ratios of grate surface to heating surface are given in the various handbooks. However, the stoker manufacturers maintain engineering departments whose technical recommendations should always be given consideration. Combustion rates for certain coals are given in Table 16.

TABLE 16.—*Combustion rates for forced-draft underfeed stokers*[1]

Operating conditions	Combustion per hour per square foot of grate area for coals designated—				
	Eastern	Pittsburgh	Illinois	Iowa	Lignite
Continuous:	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Minimum	20 to 25	25 to 28	25 to 28	25 to 28	25 to 28
Maximum	40 to 45	40 to 45	38 to 42	35 to 42	38 to 45
Recommended	30 to 38	32 to 40	30 to 38	28 to 35	30 to 35
3 to 4 hour peak:					
Maximum	60 to 65	60 to 65	50 to 55	45 to 47	50 to 55
Recommended	50 to 60	50 to 60	45 to 50	42 to 45	45 to 50
1-hour peak, maximum	70	70	60	50	60

[1] From the following publication: WORKER, J. G. CONDITIONS WHICH AFFECT OPERATION OF THE FURNACES IN YOUR BOILERS SHOULD BE GIVEN CAREFUL ATTENTION. MODERN RECORDING AND ROOM-CONTROL INSTRUMENTS AND AUTOMATIC DEVICES HAVE MADE THE CENTRALIZED OPERATION OF BOILER PLANTS FROM CONVENIENTLY PLACED INSTRUMENT BOARDS A GROWING PRACTICE. Power Plant Engin. 27 (1): 4 (Table 1). 1923.

Important facts to be considered in selecting and using stokers are: (1) Stokers in large plants, when used in conjunction with modern methods of storing and handling coal, show considerable savings in labor; (2) the use of stokers is advisable in small plants where substantial savings in fuel due to their use can be shown, or where prevention of smoke is important; (3) stokers permit the efficient use of a broad range of fuels; and (4) the upkeep cost with stokers is greater than with hand-fired furnaces.

BOILER-ROOM INSTRUMENTS AND RECORDS

One of the most striking facts revealed by the field survey of greenhouses was the comparatively small use of boiler-room instruments. This is due undoubtedly to a lack of appreciation of the value of instruments in indicating the degree of completeness of combustion and the over-all efficiency. The boiler room offers large opportunities for the accomplishment of real economies. Some firemen have at first objected to the installation of equipment which indicates how efficiently they are doing their work and how efficiently their boilers are functioning. Some use of these instruments, however, generally has demonstrated that they aid the fireman in performing his task and that in maintaining a good fire bed with proper adjustment of dampers he is lightening his labors as well as saving fuel. Boiler-room instruments almost invariably improve boiler-room morale, and even the owner of a moderately small plant will find the keeping and study of records decidedly advantageous.

While the need for boiler-room instruments may be evident, differences in conditions as well as the varying experiences and preferences of the individuals concerned create diverse opinions as to instruments needed. Obviously the size of plant affects the selection. If the coal consumption is comparatively small, the expenditure of large sums for instruments is not warranted.

Judgment is needed in the selection of boiler-room instruments, and in many instances the purchaser must rely upon the recommendation of the instrument salesman. While the use of instruments almost invariably results in saving fuel, their cost should be

justified by the savings. The owner of a very small plant is almost never justified in purchasing boiler-room instruments or expensive weighing and metering devices. This does not mean that he should not strive for efficiency in operating his plant, but rather that the amount of fuel he might save by the use of instruments and other efficiency devices would not be sufficient to justify the additional expenditure. The interest on investment, depreciation, and repair costs must be balanced against the possible savings in considering an investment in efficiency equipment.

Thermometers for determining the flue-gas temperature, of either mercury or thermoelectric type, are comparatively simple and inexpensive, and are among the most useful of boiler-room instruments. The temperature of the flue gases as they leave the boiler is an important indicator of the efficiency of operation of the boiler. If the water tubes are carrying a heavy deposit of scale on the inside or of soot on the outside, their effectiveness as regards heat absorption is reduced and much of the heat in the gases passes up the stack. Likewise, if the boiler baffle plates are in bad condition so that the hot gases are not properly directed in the boiler, heat will not be transferred adequately and a high flue-gas temperature will result. Also, if there is a hole in the fire the excess of air will be increased, which will be accompanied by a rise in the flue-gas temperature. Correction of such faulty conditions will save fuel. Because of its relatively low first cost and its simplicity, the stack-temperature instrument would prove feasible in plants of medium size.

The carbon dioxide (CO_2) content of the flue gases is an important indication of the combustion efficiency. For a given fuel this content of the flue gases increases and decreases inversely with the excess of air. Excess of air causes low furnace temperature and high temperature of exit gases from the boiler, which result in large stack loss and correspondingly low efficiency. Conversely, insufficient air results in incomplete combustion, with smoke and low efficiency. Either condition means a waste of fuel.

Instruments for indicating the carbon dioxide content of the flue gases are of two general types, the hand-operated flue-gas analyzers and the direct-reading carbon dioxide meters. The former are relatively cheap, but a certain amount of skill and time are required in using them. The direct-reading instrument is therefore more desirable in general, but the possible saving in fuel must justify the investment, and the owner of the smaller plant is not advised to invest in such relatively costly equipment.

Most of the larger greenhouse heating plants are operated with mechanical stokers. In a stoker-fired plant some type of tachometer to indicate stoker speed or rate of feeding coal is highly desirable. Such an instrument is useful to the fireman as an aid in correctly adjusting operation of the stokers to the demand for heat.

Improved equipment available to-day for large plants includes water meters, steam-flow meters, and coal-weighing apparatus. From knowledge of the weights of coal fired and of water evaporated comparative efficiencies can be estimated and any reduction in efficiency can be detected readily. In plants operating several boilers it is sometimes advantageous to measure the output of each boiler so

that the load can be distributed properly among them. Steam-flow meters are used to measure the volume of steam that is being generated by each boiler and show the percentage rating at which the boilers are working.

AUTOMATIC CONTROLS

Overheating is more common than underheating in greenhouses. Heating systems supposedly are designed to cope with the severest conditions that may occur, and these conditions exist for only short periods—perhaps a week in the year. During the rest of the season the heating apparatus must operate at less than its maximum capacity. On an average, a heating system in the colder climates operates at about 40 per cent of its maximum capacity. Gas and oil heaters, as well as some types of stokers, require thermostatic control in order to prevent overheating. On the other hand, temperature control is necessary to prevent the temperature from dropping too low, since temperatures below a certain point may result in partial or total loss of crops involving large sums. Thus, in addition to saving fuel, thermostatic control performs the extremely important function of preventing crop damage. It may also save considerable labor.

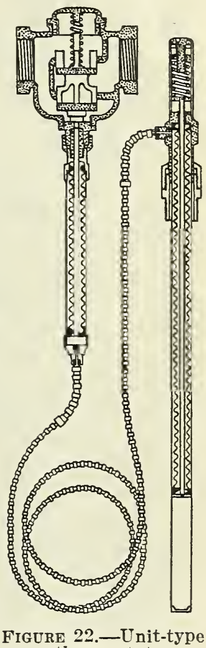

FIGURE 22.—Unit-type thermostat

Frequently a small establishment is operated by the owner with a very limited force of assistants, and at night the owner gives the heating system whatever attention may be necessary. In such a case some system of low-temperature alarm is commonly used to indicate when more heat is needed.

The simpler class of automatic temperature-control devices includes those in which the thermostats and the valves or dampers that they operate are self-contained. No outside power is utilized, sufficient energy being provided by the thermostatic element itself to operate the valve, damper, or whatever secondary control device is used. A thermostat of this class, known as the "unit" type, is shown in Figure 22. In the regulator shown a valve is actuated by means of the change in volume of the liquid.

The other and more elaborate class of automatic control is that in which the change in the thermostatic element merely controls the application of some form of energy—as electricity, or air or liquid under pressure—for the movement of the valve or damper. These devices are generally moved against the force of springs or weights which reverse the motion when the outside actuating effort ceases. This class of thermostat is known as the "pilot" type.

Figure 23 shows one type of pilot control that is well adapted to regulate greenhouse temperature, particularly in small or medium-sized plants. It is applicable to steam, water, vapor, or warm-air installations. The particular installation shown is for steam and

operates as follows: The thermostat, placed at some representative point in the greenhouse, is connected by a small electric cable with a motor in the boiler room. This thermostat contains a metal coil that is very sensitive to temperature variations. Attached to the coil is a blade that moves between two contact points. When the coil expands by heat the blade touches one contact point, closing an electric circuit and causing the motor in the boiler room to close drafts, gas valve, or other means of heat control by tightening or slackening the chains connecting them with the motor arms. When the temperature has lowered to about 1° below that desired the thermostat coil has contracted sufficiently to cause the blade to touch the other contact post, whereupon the motor operates to open the valves and allow the generation of more heat.

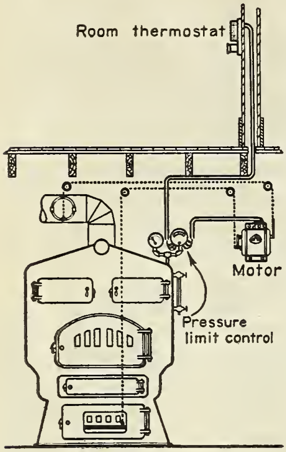

FIGURE 23.—Regulation of dampers by pilot-type thermostat

In addition to the thermostat and motor described, a safety-limit device is placed on the furnace or boiler. It is wired as a dual control with the room thermostat, and operates only in emergencies when dangerous or excessive temperatures or pressures are generated by the heating plant.

Since thermostatic control opens the dampers whenever the thermostat "calls" for heat, it is necessary that a sufficient reserve of fuel be present always and that the fuel be distributed properly on the grate in order that efficient combustion may ensue. With the ordinary flat-grate boiler if no more fuel were added during a cold night, for example, the fuel might be entirely consumed before morning. The boilers shown in Figures 15 and 16 are especially adapted to automatic temperature control by damper because the fuel feeds down from a magazine by gravity over the top of the fire bed as required.

Another example of the pilot type of thermostatic control is shown in Figure 24. In this case the control serves to start and stop a draft blower for a burner of buckwheat coal. The thermostat is placed in the greenhouse and set for the desired temperature. When the temperature drops below this point an electric circuit is completed and the blower motor starts. Thus the rate of combustion is increased and the house temperature is raised. When the desired temperature has been reached the blower motor is stopped and combustion is reduced to a very low rate, principally because of the packing of the small-size fuel. With a flat-grate boiler with which buckheat or other small-sized fuel is used, forced draft is necessary in order to pass sufficient air through the fire bed for efficient operation. The safety control to limit the boiler pressure or temperature is a highly essential part of the sys-

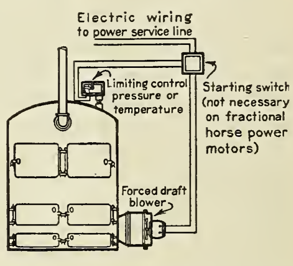

FIGURE 24.—Thermostatically-controlled blower for burning small-size anthracite

tem. The type of thermostat frequently used on this sort of installation is capable of controlling small motors directly, and the starting switch shown in Figure 24 is necessary only on motors of more than 1 horsepower.

Greenhouse-heating systems frequently are of the forced-circulation hot-water type. As already explained (p. 11), in such a system water is pumped through the flow mains into the heating coils, thence to the returns and back to the boiler to be reheated and recirculated. Obviously, if the water is heated to a definite temperature in the boiler, say, 180° F., the quantity of heat emitted from the radiators can be increased or decreased by varying the speed with which the water is circulated. Figure 25 shows a scheme by which a pilot-

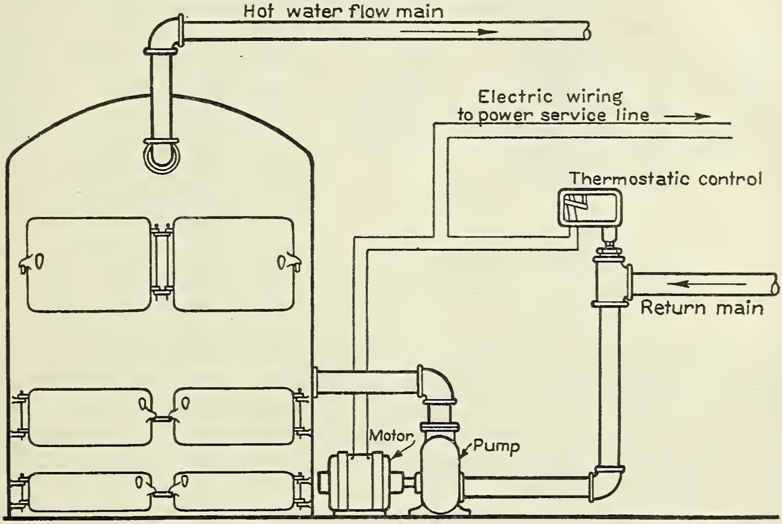

FIGURE 25.—Thermostatically controlled water circulation by means of a pump

type thermostat is utilized to control the circulating pump according to the temperature demands in the greenhouse. This scheme, when employed with means for maintaining the boiler-water temperature at a predetermined value, should give entirely effective greenhouse-temperature control.

Another example of temperature control by the pilot-type thermostat is the so-called motor valve. This valve is used in conjunction with a room thermostat of a type that is capable of carrying a small amount of electric current. With an increase in temperature, this thermostat makes an electrical contact which causes the motor valve to close. Contact on the opposite side of the thermostat causes the motor to open the valve. The valve is so designed that it can not stop in a midway position; it must be either wholly closed or wide open. Such a device placed, for example, in the steam line feeding the radiation will serve to keep the house temperature practically constant so long as there is an ample supply of steam at the valve. It can also be used to automatically start and stop a steam pump or similar auxiliary apparatus.

Stokers lend themselves readily to automatic control of boiler temperature or pressure, and even to room-temperature control, through automatic control of the speed of the stoker. Where the stoker is controlled by a room-temperature regulator some device for limiting the boiler temperature or pressure must also be used.

UNIT HEATERS

Unit heaters have been little used in greenhouses as yet. Some characteristics of unit heaters would seem to be ideal for this type of service, but no definite conclusions as to their practicability or their superiority over the ordinary type of radiation can be drawn until more tests have been made.

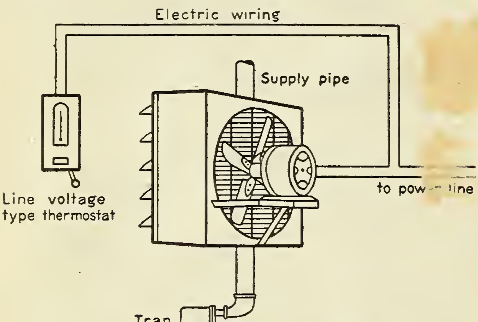

FIGURE 26.—Diagram of unit heater with thermostatic control

The unit heater consists of a heating element, generally similar to the ordinary automobile radiator, through which the heating medium—steam or hot water—is passed. Air is forced past the heating surface by means of an electrically driven fan, as shown in Figure 26. The compact heating surface and effective air circulation permit a comparatively high transfer of heat to the air. Therefore, the unit heater is very light as compared with the ordinary pipe-coil radiation, and frequently requires no more support than the vertical feed pipe which joins the heater to the supply line.

Some of the chief advantages claimed for unit heaters in greenhouses are (1) relatively uniform temperature distribution, resulting from the effect of the fan in directing the heated air downward; (2) very little shading of crops, due to small, compact heating units with only a minimum of piping; (3) ease of control, through automatic-control devices and varying the speed of the fan; (4) flexibility—the temperature can be raised or lowered quickly; and (5) a gentle air motion advantageous to crop growth provided by the circulation fan. One apparent disadvantage is the fact that continuity of operation depends upon the electric service.

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